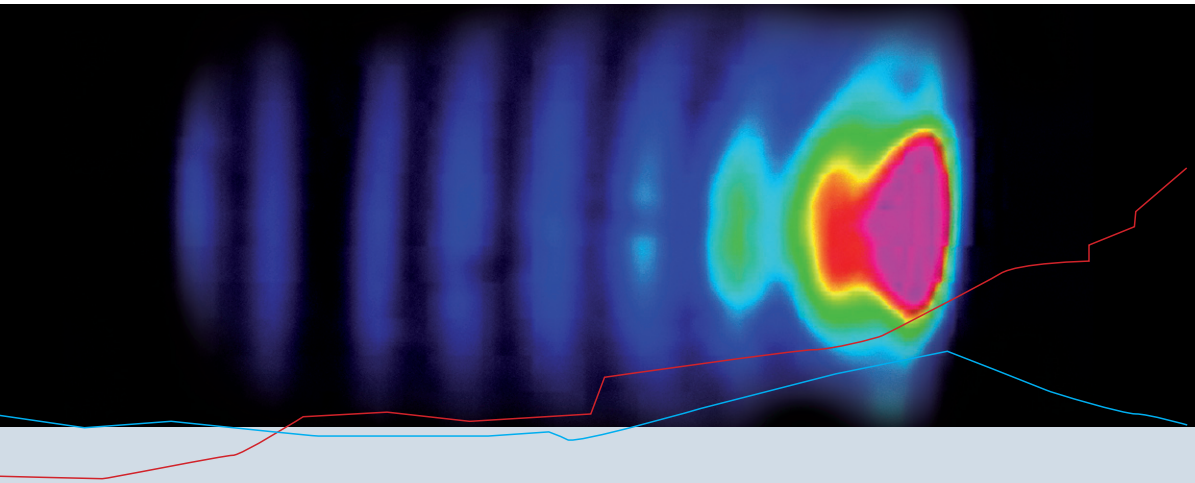
# User's manual



# FLIR R&D software 1.2

FLIR QuickPlot | FLIR ResearchIR


| | |
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# FLIR R&D software 1.2

*User's manual*

Publ. No. T559132 Rev. a449 – ENGLISH (EN) – April 21, 2010

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# Table of contents


**1 Notice to user** ..... 1

**2 Customer help** ..... 2

**3 Documentation updates** ..... 3

**4 Important note about this manual** ..... 4

**5 Installation** ..... 5
- 5.1 New features in version 1.2 SP1 ..... 5
- 5.2 System requirements ..... 6
- 5.3 Installation of FLIR R&D software ..... 7

**6 Managing licenses** ..... 8
- 6.1 Registering your product ..... 8
- 6.2 Activating your license ..... 9
- 6.3 Transferring your license ..... 11
- 6.4 Updating your product ..... 12

**7 Supported features** ..... 13
- 7.1 General ..... 13
- 7.2 Feature matrix ..... 13

**8 Getting started** ..... 19
- 8.1 Connecting a camera ..... 19
- 8.2 Acquiring an image or sequence file in real-time ..... 20
- 8.3 Adjusting the image or sequence file ..... 21
- 8.4 Saving a sequence file or an image snapshot ..... 22
- 8.5 Locating images or sequence files ..... 23
- 8.6 Viewing images or sequence files ..... 24

**9 Overview of screen elements** ..... 25
- 9.1 Organize tab ..... 26
- 9.2 Analyze tab ..... 28
  - 9.2.1 Analyze tab > Camera tab ..... 28
  - 9.2.2 Analyze tab > Recording tab ..... 30
  - 9.2.3 Analyze tab > Recording tab (detail view of start/stop) ..... 31
  - 9.2.4 Analyze tab > Storage tab ..... 33
- 9.3 Image window ..... 35
  - 9.3.1 Image window > Measurement toolbar ..... 36
  - 9.3.2 Image window > Sequence recording toolbar ..... 38
  - 9.3.3 Image window > Sequence playback toolbar ..... 39
- 9.4 Plot window ..... 40
  - 9.4.1 Plot window > Plot toolbar ..... 41
- 9.5 Profile window ..... 42
  - 9.5.1 Profile window > Profile toolbar ..... 43
- 9.6 Zoom & Pan pane ..... 44
- 9.7 Scale pane ..... 45
- 9.8 Results pane ..... 47

**10 Recording sequence files** ..... 48

10.1 How to set the recording speed ... 48
10.2 How to set a prerecording ... 49
10.3 How to set a start trigger ... 50
10.4 How to set a stop trigger ... 51
10.5 How to set a postrecording ... 52

**11 Working with plots** ... 53

**12 Working with profiles** ... 54

**13 Exporting data** ... 55

**14 Changing settings** ... 56
14.1 Changing program settings ... 56
14.2 Changing object parameters ... 57
14.2.1 Changing object parameters globally ... 57
14.2.2 Changing object parameters locally ... 58

**15 About FLIR Systems** ... 59
15.1 More than just an infrared camera ... 60
15.2 Sharing our knowledge ... 60
15.3 Supporting our customers ... 60
15.4 A few images from our facilities ... 61

**16 Glossary** ... 63

**17 Thermographic measurement techniques** ... 67
17.1 Introduction ... 67
17.2 Emissivity ... 67
17.2.1 Finding the emissivity of a sample ... 68
17.2.1.1 Step 1: Determining reflected apparent temperature ... 68
17.2.1.2 Step 2: Determining the emissivity ... 70
17.3 Reflected apparent temperature ... 71
17.4 Distance ... 71
17.5 Relative humidity ... 71
17.6 Other parameters ... 71

**18 History of infrared technology** ... 72

**19 Theory of thermography** ... 76
19.1 Introduction ... 76
19.2 The electromagnetic spectrum ... 76
19.3 Blackbody radiation ... 77
19.3.1 Planck's law ... 78
19.3.2 Wien's displacement law ... 79
19.3.3 Stefan-Boltzmann's law ... 81
19.3.4 Non-blackbody emitters ... 82
19.4 Infrared semi-transparent materials ... 84

**20 The measurement formula** ... 86

**21 Emissivity tables** ... 92
21.1 References ... 92
21.2 Important note about the emissivity tables ... 92
21.3 Tables ... 93

# 1 Notice to user

**Typographical conventions**

This manual uses the following typographical conventions:

- **Semibold** is used for menu names, menu commands and labels, and buttons in dialog boxes.
- *Italic* is used for important information.
- `Monospace` is used for code samples.
- UPPER CASE is used for names on keys and buttons.

**User-to-user forums**

Exchange ideas, problems, and infrared solutions with fellow thermographers around the world in our user-to-user forums. To go to the forums, visit:

http://www.infraredtraining.com/community/boards/

**Training**

To read about infrared training, visit:

- http://www.infraredtraining.com
- http://www.irtraining.com
- http://www.irtraining.eu

**Additional license information**

This license permits the user to install and use the software on any compatible computer, provided the software is used on a maximum of two (2) computers at the same time (for example, one laptop computer for on-site data acquisition, and one desktop computer for analysis in the office).

One (1) back-up copy of the software may also be made for archive purposes.

# 2 Customer help

**General**

For customer help, visit:

http://flir.custhelp.com

**Submitting a question**

To submit a question to the customer help team, you must be a registered user. It only takes a few minutes to register online. If you only want to search the knowledge-base for existing questions and answers, you do not need to be a registered user.

When you want to submit a question, make sure that you have the following information to hand:

- The camera model
- The camera serial number
- The communication protocol, or method, between the camera and your PC (for example, HDMI, Ethernet, USB™, or FireWire™)
- Operating system on your PC
- Microsoft® Office version
- Full name, publication number, and revision number of the manual

**Downloads**

On the customer help site you can also download the following:

- Firmware updates for your infrared camera
- Program updates for your PC software
- User documentation
- Application stories
- Technical publications

# 3 Documentation updates

**General**

Our manuals are updated several times per year, and we also issue product-critical notifications of changes on a regular basis.

To access the latest manuals and notifications, go to the Download tab at:

http://flir.custhelp.com

It only takes a few minutes to register online. In the download area you will also find the latest releases of manuals for our other products, as well as manuals for our historical and obsolete products.

# 4 Important note about this manual

**NOTE** FLIR Systems reserves the right to discontinue models, software, parts or accessories, and other items, or to change specifications and/or functionality at any time without prior notice.

# 5 Installation

## *5.1 New features in version 1.2 SP1*

**List of features**

- Translation of software interface to Simplified Chinese
- Translation of software interface to Traditional Chinese
- Support for UVC. For more information about UVC support, see below.

**What is UVC?**

UVC is an acronym for *USB Video Class* and is a device class describing devices that are capable of streaming video.

The advantages of UVC compared to other streaming video protocols include the following:

- Built-in class driver support starting from Microsoft® Windows® XP, Service Pack 2
- Higher speed than IP-based streaming protocols, e.g., RTP (*Real-time Transport Protocol*)

The USB device function can be set in the camera (subject to infrared camera model).

## 5.2 System requirements

**Required operating system**

One of the following:

- Microsoft® Windows® XP Pro, with Service Pack 3 (SP3), 32-bit
- Microsoft® Windows® Vista, with Service Pack 1 (SP1), 32-bit
- Microsoft® Windows® Vista, with Service Pack 1 (SP1), 64-bit
- Microsoft® Windows® 7, 32-bit
- Microsoft® Windows® 7, 64-bit

**Recommended camera models and camera software releases**

For a list of recommended and supported cameras, and camera software releases, go to http://flir.custhelp.com.

**Required hardware**

- Personal computer with an Intel® 2GHz MHz Pentium processor (dual core) or an AMD Opteron, AMD Athlon 64, or AMD Athlon XP processor (dual core)
- 1 GB of RAM, or greater
- 20 GB of available hard disk space
- CD-ROM drive
- Support for DirectX 9 graphics with:
  - WDDM driver
  - 128 MB of graphics memory (minimum)
  - Pixel Shader 2.0 in hardware
  - 32 bits per pixel
- Super VGA (1024 × 768) monitor (minimum, 1400× or higher recommended)
- Internet access (fees may apply)
- Audio output
- Keyboard and Microsoft® mouse, or a compatible pointing device

## 5.3 Installation of FLIR R&D software

**NOTE**

- You must be an Administrator or a user with Administrative Rights to install the program.
- A complete installation consists of several subinstallations, some of which are from third party vendors. Do not abort these subinstallations, as they are needed for the complete installation.
- A complete installation may take up to 30 minutes to complete.
- At a certain time during the installation, Microsoft® warns repeatedly that the software has not passed Windows® Logo testing. In all cases, select Continue Anyway. There is no risk involved with this.
- If you are asked to restart the computer during the installation, do so without removing the CD-ROM. The installation will resume after you have restarted.

**Procedure**

Follow this procedure to install FLIR R&D software:

| | |
|---|---|
| 1 | Close down all applications. |
| 2 | Insert the FLIR R&D software software CD-ROM into the CD-ROM drive on the computer. The installation should start automatically.<br>Should the installation not start automatically, start Windows® Explorer and double-click SETUP.EXE on the CD-ROM. |
| 3 | Follow the on-screen instructions. |

# 6 Managing licenses

## *6.1 Registering your product*

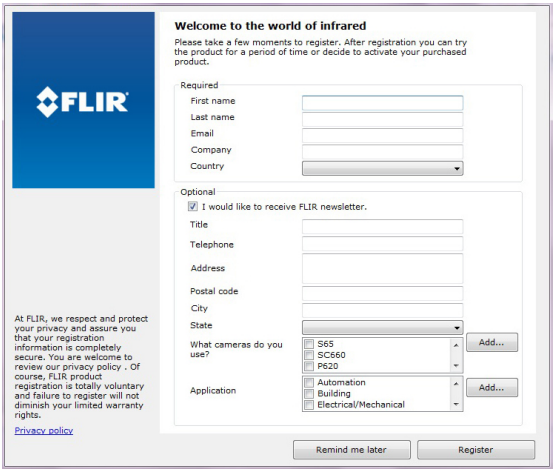
**General**

It is important that you register your product. By registering your product you are entitled to:

- Free program updates
- Free unlimited technical support at http://flir.custhelp.com
- Timely information about new releases

**Figure**

T638251;a1




**Procedure**

To register your product, fill in the required fields and click **Register**.

## 6.2 Activating your license

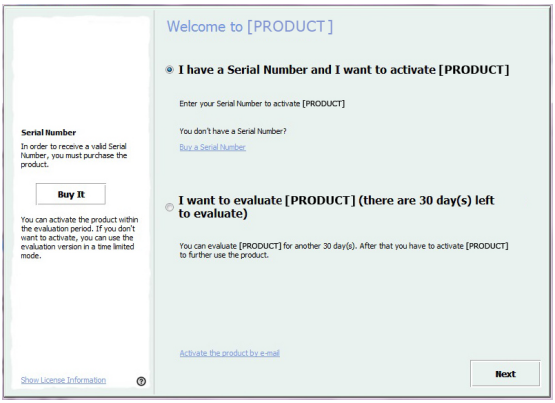
**General**

The first time you start FLIR R&D software you will be able to choose one of the following options:

- Activate FLIR R&D software online.
- Activate FLIR R&D software by e-mail.
- Purchase FLIR R&D software and receive a serial number for activation.
- Use FLIR R&D software for free during an evaluation period.

**Figure**

T638252;a1



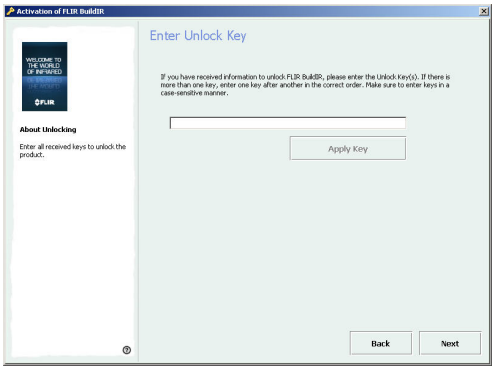

**Activating FLIR R&D software online**

Follow this procedure:

| | |
|---|---|
| 1 | Start FLIR R&D software. |
| 2 | In the web activation dialog box, select **I have a Serial Number and I want to activate FLIR R&D software**. |
| 3 | Click **Next**. |
| 4 | Enter your serial number, name, company and e-mail address. The name should be the name of the license holder. |
| 5 | Click **Next**. |
| 6 | Click **Activate now**. This will start the web activation process. |
| 7 | When the message **Online activation was successful** is displayed, click **Close**.<br>You have now successfully activated FLIR R&D software. |

**Activating FLIR R&D software by e-mail**

Follow this procedure:

| | |
|---|---|
| 1 | Start FLIR R&D software. |
| 2 | In the web activation dialog box, click **Activate the product by e-mail**. |
| 3 | Enter your serial number, name, company and e-mail address. The name should be the name of the license holder. |
| 4 | Click **Request Unlock Key by E-mail**. |
| 5 | Your default e-mail client now opens and an unsent e-mail with license information is displayed. **Send this e-mail without altering the content**.<br>The main purpose of the e-mail is to send the license information to the activation center. |
| 6 | Click **Next**. The program will now start and you can continue working while waiting for the unlock key. You should receive an e-mail with the unlock key within two days. |
| 7 | When the e-mail with the unlock key arrives, start the program and enter the unlock key in the text box. See the figure below.<br>T638430;a1<br>  |

## 6.3 Transferring your license

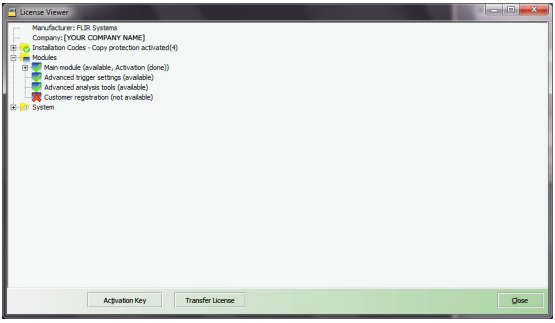
**General**

You can transfer a license from one computer to another computer, as long as you do not exceed the number of purchased licenses on one computer at the same time.

This lets you use the software on, for example, a desktop and a laptop computer.

**Figure**

T638254;a1




**Procedure**

Follow this procedure to transfer a license:

| | |
|---|---|
| 1 | Start FLIR R&D software. |
| 2 | On the **Help** menu, select **Show license information**. This will display the license viewer shown above. |
| 3 | In the license viewer, click **Transfer license**. This will display a deactivation dialog box. |
| 4 | In the a deactivation dialog box, click **Deactivate**. |
| 5 | On the computer to which you want to transfer the license, start FLIR R&D software.<br>As soon as the computer gets Internet access, the license will be automatically adopted. |

**NOTE**

The adoption of licenses is based on a “first-come, first-serve” concept. This means that the *first* computer that gets Internet access automatically adopts the transferred license.

## 6.4 Updating your product

**General**

We regularly issue software updates and you can update the program using this update service.

**Procedure**

Follow this procedure to check for updates:

| | |
|---|---|
| 1 | On the **Start** menu, select **Programs** > **FLIR Systems** > **FLIR R&D software** > **Check for updates**. |
| 2 | Follow the on-screen instructions. |

**NOTE**

Some programs from FLIR Systems also support updating from within the application.

# 7 Supported features

## 7.1 General

This table lists the features that are available in FLIR QuickPlot and FLIR ResearchIR.

## 7.2 Feature matrix

**Note:** This feature matrix is subject to change without further notice.

| Camera support | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| A20 | 9 Hz | 60 Hz |
| A40 | 9 Hz | 60 Hz |
| A320 | 2 Hz | 7–8 Hz |
| A325 | 9 Hz | 60 Hz max. |
| i60 | 1 Hz | 1 Hz |
| S65 | 9 Hz | 60 Hz |
| SC600-series windowing | – | 120 Hz max. |
| SC640 | 9 Hz | 30 Hz max. |
| T250 | 2 Hz | 3–5 Hz |
| T400 | 2 Hz | 3–5 Hz |

| Data system support | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| Desktop | + | + |
| Laptop | + | + |

| Operating system support | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| Windows® 7, 32-bit | + | + |
| Windows® 7, 64-bit | + | + |
| Windows® Vista, 32-bit | + | + |
| Windows® Vista, 64-bit | + | + |
| Windows® XP, 32-bit | + | + |

| Product focus | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| Automation | + | + |

| Product focus | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| Industrial R&D | + | + |
| Thermography | + | + |

| General | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| Toolbox | + | + |
| Plugin support | + | + |
| Camera control: | + | + |
| ☐ Connect to and control cameras | + | + |
| ☐ Camera auto-connect | + | + |
| ☐ Camera auto-reconnect | + | + |
| ☐ Camera information | + | + |
| Workspaces: | + | + |
| ☐ Default workspace | + | + |
| Local time and temperature units | + | + |
| Multiple languages: | + | + |
| ☐ English | + | + |
| ☐ Japanese | + | + |
| ☐ Simplified Chinese | + | + |
| ☐ Traditional Chinese | + | + |

| Organize and file explorer | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| Quick Collection | + | + |
| Preview of sequences | + | + |

| User interface and live view | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| Zooming | + | + |
| Pan | + | + |
| Color bar | + | + |
| Full-screen display | + | + |
| Dual-screen display | + | + |

| User interface and live view | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| Thumbnail viewer | + | + |
| Multiple viewports with live image/stored image/plots | + | + |
| Palettes | + | + |
| Inverted palettes | + | + |
| Hide/show overlay | + | + |
| Image flip H/V | + | + |
| Image enhancement: | + | + |
| ☐ Level & span: | + | + |
| ☐ ☐ Manual | + | + |
| ☐ ☐ From image | + | + |
| ☐ Scale modes: | + | + |
| ☐ ☐ Linear | + | + |
| ☐ ☐ Histogram equalization | + | + |
| Default workspace | + | + |
| NUC on/off | + | + |
| Perform NUCs: | + | + |
| ☐ One-point | + | + |

| Analysis and results | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| Flying spotmeter | + | + |
| Object parameters (global and per ROI) | + | + |
| ROIs: | + | + |
| ☐ Maximum number of ROIs | 4 | Unlimited |
| ☐ Spot | + | + |
| ☐ Box | + | + |
| ☐ Ellipse | + | + |
| ☐ Line | – | + |
| ☐ Cursor | – | + |
| ☐ Polygon | – | + |

| Analysis and results | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| ☐ Isotherm (above, below, interval) | + | + |
| Edit properties | + | + |
| Result table: | + | + |
| ☐ Mean | + | + |
| ☐ Max. | + | + |
| ☐ Min. | + | + |
| ☐ Diff. any | + | + |
| Units: | + | + |
| ☐ Raw counts | – | + |
| ☐ Object signal | – | + |
| ☐ Temperature: | + | + |
| ☐ ☐ Celsius | + | + |
| ☐ ☐ Fahrenheit | + | + |
| ☐ ☐ Kelvin | + | + |
| Graphs: | + | + |
| ☐ Plot: | + | + |
| ☐ ☐ Time vs. temp./intensity any result | + | + |
| ☐ ☐ Live plot | + | + |
| ☐ ☐ Cursor with replay | + | + |
| ☐ Profile: | + | + |
| ☐ ☐ Cursor with marker in image | + | + |

| Recording and playback | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| IR image | + | + |
| Record rate limit | + | + |
| Adjustable record rate | + | + |
| With display | + | + |
| Snapshot | + | + |
| Recording to disk: | + | + |

| Recording and playback | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| ☐ Frames per second | + | + |
| ☐ Interval (S:M:H) | + | + |
| Trigger: | + | + |
| ☐ Start: | + | + |
| ☐ ☐ Manual | + | + |
| ☐ ☐ On time | – | + |
| ☐ ☐ Conditional (above, below, interval of analysis result): | – | + |
| ☐ ☐ A325 digital in | – | + |
| ☐ Stop: | + | + |
| ☐ ☐ Manual | + | + |
| ☐ ☐ On time | – | + |
| ☐ ☐ Delta time (S:M:H) | – | + |
| ☐ ☐ Conditional (above, below, interval of analysis result) | – | + |
| ☐ ☐ A325 digital in | – | + |
| Pre/post-recording: | – | + |
| ☐ Delta time (S:M:H) | – | + |
| Playback: | + | + |
| ☐ Variable speed | + | + |
| File support: | + | + |
| ☐ Radiometric JPEGs | + | + |
| ☐ *.seq files | + | + |
| ☐ Still image from camera | + | + |

| Export | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| Graphs: | + | + |
| ☐ Image: | + | + |
| ☐ ☐ To file: | + | + |
| ☐ ☐ ☐ Single image | – | + |

| Export | FLIR QuickPlot | FLIR ResearchIR |
|---|---|---|
| ☐ ☐ ☐ Sequence (*.csv; delimited) | – | + |
| ☐ ☐ ☐ *.bmp | + | + |
| ☐ ☐ ☐ *.jpg | + | + |
| ☐ ☐ To clipboard: | + | + |
| ☐ ☐ ☐ Picture | + | + |
| ☐ ☐ ☐ Data (*.csv; delimited) | – | + |
| ☐ Plot: | + | + |
| ☐ ☐ To file: | + | + |
| ☐ ☐ ☐ *.csv; delimited | + | + |
| ☐ ☐ ☐ *.bmp | + | + |
| ☐ ☐ ☐ *.jpg | + | + |
| ☐ ☐ To clipboard: | + | + |
| ☐ ☐ ☐ Picture | + | + |
| ☐ ☐ ☐ Data (*.csv; delimited) | + | + |
| ☐ Profile: | + | + |
| ☐ ☐ To file: | + | + |
| ☐ ☐ ☐ *.csv; delimited | + | + |
| ☐ ☐ ☐ *.bmp | + | + |
| ☐ ☐ ☐ *.jpg | + | + |
| ☐ ☐ To clipboard: | + | + |
| ☐ ☐ ☐ Picture | + | + |
| ☐ ☐ ☐ Data (*.csv; delimited) | + | + |

# 8 Getting started

## *8.1 Connecting a camera*

**General**

You can connect a camera to your computer or your network, using one of the following methods:

- Ethernet
- FireWire
- USB

If you have followed the installation instruction, connecting a camera will be a plug-and-play procedure and the camera will be displayed when you click the button in the bottom left corner of the program screen.

**Recommended camera models**

- FLIR A320
- FLIR A325
- FLIR i60
- FLIR T250
- FLIR T400
- FLIR SC620
- FLIR SC640
- FLIR SC660
- ThermaCAM™ S65
- ThermoVision™ A20
- ThermoVision™ A40

Subject to change without further notice.

**NOTE**

- Your firewall may block access to the camera. If so, allow access. There is no risk involved with this.

## 8.2 Acquiring an image or sequence file in real-time

**General**

This section describes how you choose images and files using the file explorer pane. Using this method you can only work with images and sequence files in one folder at a time.

**Procedure**

Follow this procedure:

| | |
|---|---|
| 1 | Start the program. |
| 2 | To select a camera, click the button in the bottom left corner and choose the camera you want to use. The image will be automatically displayed in the image window. |

**NOTE**

- When you start the program the next time, the last connected camera will be displayed in the live source control. To connect this camera, click **Connect**, or use the right-click menu.
- For an explanation of screen elements, see section 9 – Overview of screen elements on page 25.

## 8.3 Adjusting the image or sequence file

**General**

You can adjust an image or sequence file using three different adjustment methods, and you may likely need to try different methods to see which one suits your application the best.

**Adjustment methods**

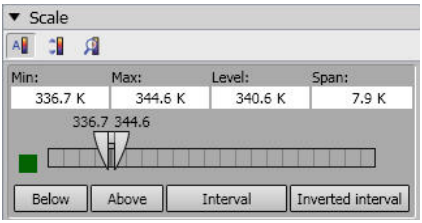
You can choose between the following adjustment methods:

1 **Auto**: The image or sequence file is automatically adjusted to best image brightness and contrast.
2 **Min**/**max**: The upper and lower temperature values are set explicitly, by using sliders or entering values in text boxes.
3 **Level**/**Span**: The temperature level is set explicitly, by using sliders or entering values in text boxes, and the span is set in the same way.

Note that method 2 and 3 are identical with regard to what they do to the image or sequence file, but let you enter values in different ways.

**Figure**

T630412;a3




**Procedure**

Follow this procedure:

| | |
|---|---|
| 1 | Go to the the **Scale** pane. |
| 2 | Do one of the following:<br>▪ Click to auto-adjust the image.<br>▪ Enter values for **Min**/**max** or **Level**/**Span**. |

**NOTE**

For an explanation of screen elements, see section 9 – Overview of screen elements on page 25.

## 8.4 Saving a sequence file or an image snapshot

**About saving a sequence file**

Prior to recording, you need to specify where you want to save your sequence files. You do this on the **Storage** tab.

When you have specified the path, the recorded sequence files will be saved in this location.

**About saving an image snapshot**

During recording of a sequence file, you can at any time save an image snapshot as a *.jpg file. You do this by clicking the button on the recording toolbar. This saves the image snapshot to the designated location.

**NOTE**

For an explanation of screen elements, see section 9 – Overview of screen elements on page 25.

## 8.5 Locating images or sequence files

**Procedure**

Follow this procedure:

| | |
|---|---|
| 1 | Click the **Organize** tab |
| 2 | To locate your images or sequence files, use the file explorer in the same way as you use Windows' file explorer. You can expand folders, select external drives, etc. |
| 3 | (Optional)<br>To add an image or sequence file to the Quick Collection for later analysis, move the file to the Quick Collection pane using the right-click menu or a drag-and-drop operation. |

**NOTE**

For an explanation of screen elements, see section 9 – Overview of screen elements on page 25.

## 8.6 Viewing images or sequence files

**General**

This procedure assumes that you have carried out Step 3 in the previous procedure.

**Procedure**

Follow this procedure:

In the Quick Collection pane, move the image or sequence file to the image window by double-clicking, using the right-click menu or using a drag-and-drop operation.

You can now view or play the file in the image window.

**NOTE**

For an explanation of screen elements, see section 9 – Overview of screen elements on page 25.

# 9 Overview of screen elements

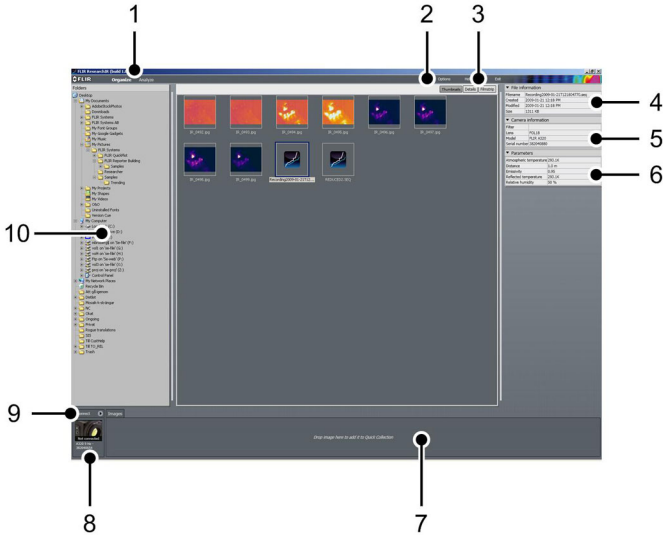
**General**

- Many functions and tools have tooltips that display basic help information. To display the tooltips, hold the cursor over the function or tool in question.
- To display the online Help, press F1.

# 9.1 *Organize* tab

**Figure**

T630400;a1




**Explanation**

This table explains the figure above:

| | |
|---|---|
| 1 | Main tab bar:<br>▪ **Organize**<br>▪ **Analyze** |
| 2 | Main menu bar:<br>▪ **Options**<br>▪ **Help**<br>▪ **Exit** |
| 3 | Buttons to change the file view:<br>▪ **Thumbnails**<br>▪ **Details**<br>▪ **Filmstrip** |
| 4 | File information pane.<br>Information about the selected file, such as its filename, when it was created, when it was modified, etc. |

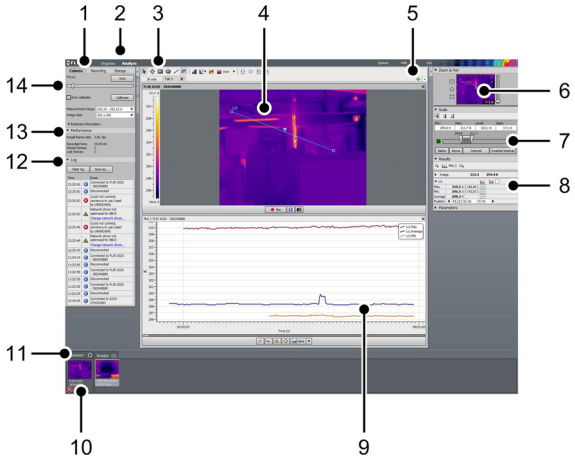
| | |
|---|---|
| 5 | Camera information pane.<br>Information about the camera from which the selected file originates, such as the camera model, its lens, its serial number, etc. |
| 6 | Parameters pane.<br>Object parameters and their current values for the selected file. |
| 7 | Quick Collection pane (also visible on the **Analyze** tab).<br>The Quick Collection pane is a collection of shortcuts to the original files. Hence, the Quick Collection can contain files that reside in different locations on your computer or network. |
| 8 | Live source control (also visible on the **Analyze** tab).<br>The live source control displays a thumbnails of the image from the currently connected camera, together with the camera name. |
| 9 | **Connect**/**Disconnect** button (also visible on the **Analyze** tab).<br>You use the **Connect**/**Disconnect** button to connect or disconnect cameras from the application. To see all cameras on the network, click the button in the bottom left corner. |
| 10 | Explorer pane.<br>The explorer pane works in the same way as Windows® Explorer. You can expand folders, select external drives, etc. |

# 9.2 *Analyze tab*

## 9.2.1 Analyze tab > Camera tab

**Figure**

T630401;a2




**Explanation**

This table explains the figure above:

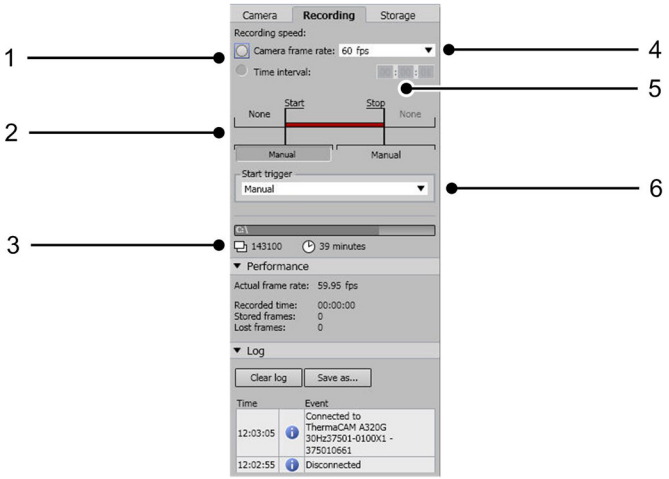
| | |
|---|---|
| 1 | **Analyze** subtabs:<br>▪ **Camera**<br>▪ **Recording**<br>▪ **Storage** |
| 2 | Main tab bar:<br>▪ **Organize**<br>▪ **Analyze** |
| 3 | Measurement toolbar.<br>You use this toolbar to add measurement tools to the image, such as spots, lines, areas, isotherms, etc. |
| 4 | Image window.<br>This image window is where the image from the currently connected camera, or an image file on your computer or network, is displayed. |
| 5 | Buttons to add more image window tabs, and to select the different tabs. |

| | |
|---|---|
| 6 | **Zoom & Pan** pane.<br>You use the **Zoom & Pan** pane to change the zoom factor, and to pan over images. |
| 7 | **Scale** pane.<br>You use the **Scale** pane to carry out various adjustments on the image. You can choose between several different adjustment methods, and also assign a color to display portions of the image that lie above or below a set temperature level, or inside a set temperature interval. |
| 8 | **Results** pane.<br>The results pane displays the results of any measurement tools that you have laid out in the image. This pane also displays the position of each measurement tool, and controls in which way you want to plot temperatures in a plot window. |
| 9 | Plot window.<br>The plot window displays how the temperature changes over time in a recorded sequence file. In this area you can set various options, such as background and foreground color, etc. |
| 10 | Live source control (also visible on the **Organize** tab).<br>The live source control displays a thumbnails of the image from the currently connected camera, together with the camera name. |
| 11 | **Connect**/**Disconnect** button (also visible on the **Analyze** tab).<br>You use the **Connect**/**Disconnect** button to connect or disconnect cameras from the application. To see all cameras on the network, click the button in the bottom left corner. |
| 12 | **Log** area.<br>The log area displays all events that occur during the time a camera is connected. You can clear the log, and also export the log data as an HTML or XML file. |
| 13 | **Performance** area.<br>The **Performance** area displays the performance of the currently connected camera. Here you can review the frame rate, recording time, number of stored and lost image frames, etc. |
| 14 | This area displays parameters, such as focus, calibration, measurement range, image size, etc. |

## 9.2.2 Analyze tab > Recording tab

**Figure**

T630403;a2




**Explanation**

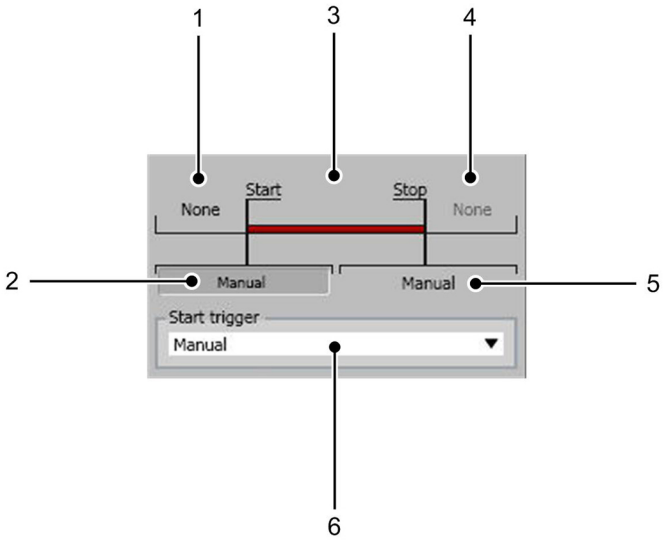
This table explains the figure above:

| | |
|---|---|
| 1 | Controls to set the recording speed:<br>■ According to the camera frame rate.<br>■ According to the time interval between saved image frames. |
| 2 | Controls to set start/stop triggers (see next section). |
| 3 | ■ The horizontal bar indicates the relative available space on your hard disk drive that you can use to save image frames.<br>■ The left icon indicates the same information, but as the number of image frames, assuming that no settings are changed.<br>■ The right icon indicates the same information, but as the minutes, assuming that no settings are changed. |
| 4 | Drop-down box to select camera frame rate. |
| 5 | Time interval selection boxes. |
| 6 | Drop-down box to select the start/stop trigger (see the next section). |

## 9.2.3 Analyze tab > Recording tab (detail view of start/stop)

**Figure**

T630402;a2




**Explanation**

This table explains the figure above:

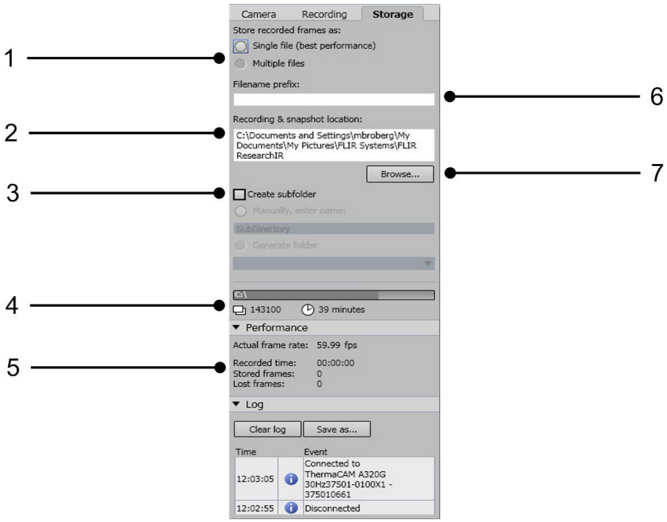
| | |
|---|---|
| 1 | Prerecording button (currently displayed as **None**).<br>A prerecording is a defined number of image frames that are stored before the actual event that triggers the recording takes place. The image frames in a prerecording are retrieved from a looping image buffer.<br>In many situations, a prerecording is necessary in order to carry out a successful analysis of the recorded event. A prerecording also provides a full history of the event that triggers the start of the recording.<br>You set the prerecording as a time interval. |
| 2 | Button for Start trigger parameters (currently displayed as **Manual**).<br>You can choose from several different methods to set up a start trigger:<br>▪ **Manual**: To start the recording manually.<br>▪ **Date & Time**: To set a date and time when the recording will start.<br>▪ **Conditional**: To set a condition to start the recording, e.g. that the recording will start when the maximum temperature in the image falls below a defined temperature. (This assumes that you have previously laid out measurement tools in the image.)<br>▪ **External trigger**: To let the digital input in FLIR A325 start the recording. |
| 3 | The red line indicates the actual recording phase (of symbolic use only). |

| | |
|---|---|
| 4 | Postrecording button (currently displayed as **None**).<br>A postrecording is a defined number of image frames that are stored after the recording that an event has triggered. The image frames in a postrecording are retrieved from a looping image buffer.<br>In many situations, a postrecording is necessary in order to carry out a successful analysis of the recorded event. A postrecording also provides a full history of the event that triggers the stop of the recording.<br>You set the prerecording as a time interval. |
| 5 | Button for Stop trigger parameters (currently displayed as **Manual**).<br>You can choose from several different methods to set up a stop trigger:<br>▪ **Manual**: To stop the recording manually.<br>▪ **Date & Time**: To set a date and time when the recording will stop.<br>▪ **Duration**: To set a time interval after which the recording will stop.<br>▪ **Conditional**: To set a condition to stop the recording, e.g. that the recording will stop when the maximum temperature in the image falls below a defined temperature. (This assumes that you have previously laid out measurement tools in the image.) |
| 6 | List box to select the trigger type. |

## 9.2.4 Analyze tab > Storage tab

**Figure**

T630404;a2




**Explanation**

This table explains the figure above:

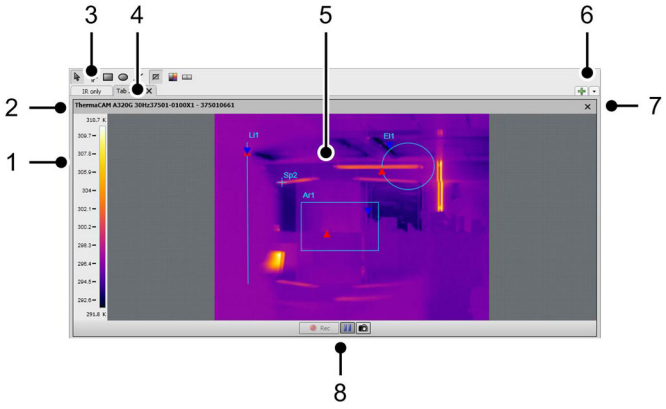
| | |
|---|---|
| 1 | Option buttons that control how the recorded files will be saved:<br>▪ **Single file** (*.seq)<br>▪ **Multiple files** (*.fff) |
| 2 | The location where the files will be saved. You can choose a different location by clicking the **Browse** button. |
| 3 | **Create subfolder** check box.<br>If you select this check box, you can choose to manually create a subfolder in the previously selected location, or to have the program automatically generate subfolders according to various date formats. |
| 4 | ▪ The horizontal bar indicates the relative available space on your hard disk drive that you can use to save image frames.<br>▪ The left icon indicates the same information, but as the number of image frames, assuming that no settings are changed.<br>▪ The right icon indicates the same information, but in minutes, assuming that no settings are changed. |

| | |
|---|---|
| 5 | The **Performance** group displays the following information:<br>■ **Actual frame rate**<br>■ **Stored frames**<br>■ **Lost frames** |
| 6 | **Filename prefix** text box.<br>Here you can define an alphanumerical prefix that will be added to all recorded files. |
| 7 | **Browse** button. You use this button to select a new location to save files. |

## 9.3 Image window

**Figure**

T630405;a1




**Explanation**

This table explains the figure above:

| | |
|---|---|
| 1 | Temperature scale. |
| 2 | Camera identity (or to the file path for images or sequence files on the disk). |
| 3 | Measurement toolbar. |
| 4 | Image window tabs. |
| 5 | Image window, with example measurement tools (spot, line, rectangle, circle). |
| 6 | Buttons to add more image window tabs, and to select existing image window tabs (if more than one). |
| 7 | Close button. |
| 8 | Recording toolbar. |

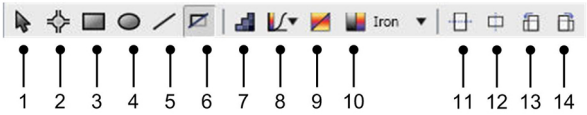
**NOTE**

You can go between normal window and full screen by pressing F11.

## 9.3.1 Image window > Measurement toolbar

**Figure**

T630406;a3




**Explanation**

This table explains the figure above:

| | |
|---|---|
| 1 | Select tool.<br>You use this tool when you want to move spots, areas, and lines within an image. |
| 2 | Spotmeter tool.<br>You use this tool to create a spotmeter that you can put anywhere on the image. The spotmeter and the temperature it displays will be stored with the image when you save it.<br>To move the spotmeter, use the Select tool to select the spotmeter tool, then click-drag the tool. |
| 3 | Area tool.<br>You use this tool to click-and-drag within the image to create an area. The minimum and maximum temperatures in the area will be displayed in the measurement results table.<br>To move the area, use the Select tool to select the area tool, then click-drag the tool. |
| 4 | Circle/ellipse tool.<br>You use this tool to click-and-drag within the image to create a circle. The minimum and maximum temperatures in the area will be displayed in the measurement results table.<br>To move the circle, use the Select tool to select the circle tool, then click-drag the tool. |
| 5 | Line/polyline tool.<br>You use this tool to create a line within the image. The minimum and maximum temperatures along the line will be displayed in the measurement results table.<br>To move the line, use the Select tool to select the line tool, then click-drag the tool. |
| 6 | Show/hide overlay graphics tool.<br>You use this tool to display and hide the overlay graphics that are associated with the image from the infrared camera. |

| | |
|---|---|
| 7 | Tool to enable/disable the “nearest neighbor” image interpolation algorithm.<br>When you zoom into an image, FLIR R&D software uses a bicubic image interpolation algorithm that gives a smooth transition between the pixels.<br>In some situations, you want to see the transitions between the pixels clearly, and to do that you use the “nearest neighbor” image interpolation algorithm |
| 8 | Tool to select color distribution mode:<br>■ Linear<br>■ Enhanced contrast |
| 9 | Tool to invert the selected palette. |
| 10 | Palette tool.<br>You use this tool to change the color palette within an image. |
| 11 | Tool to mirror the image and measurement tools horizontally. |
| 12 | Tool to mirror the image and measurement tools vertically. |
| 13 | Tool to rotate the image and measurement tools to 90° to the left. |
| 14 | Tool to rotate the image and measurement tools to 90° to the right. |

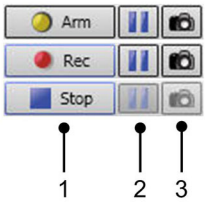
## 9.3.2 Image window > Sequence recording toolbar

**NOTE**

- The top row shows what the toolbar looks like before the recording has started and before the trigger has been armed.
- The middle row shows what the toolbar looks like before the recording has started and during pause.
- The bottom row shows what the toolbar looks like during recording

**Figure**

T630407;a1




**Explanation**

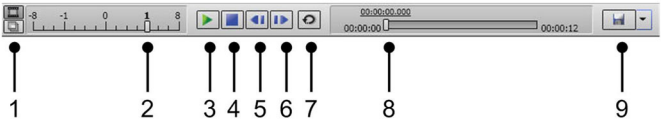
This table explains the figure above.

| | |
|---|---|
| 1 | **Arm**/**Disarm**/**Rec**/**Stop** button. |
| 2 | Pause button. |
| 3 | Button to save a single snapshot as a *.jpg file. |

## 9.3.3 Image window > Sequence playback toolbar

**Figure**

T630423;a1




**Explanation**

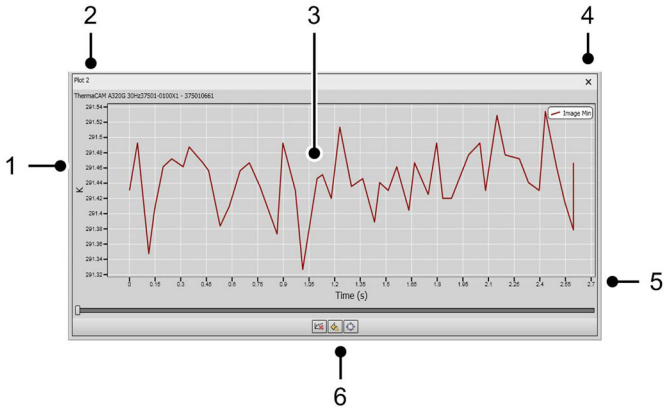
This table explains the figure above.

| | |
|---|---|
| 1 | Buttons to switch between film mode playback and slide mode playback. |
| 2 | Scale to set playback × recorded speed. |
| 3 | Play/pause button. |
| 4 | Stop button. |
| 5 | Button to go back one image frame at a time. |
| 6 | Button to go forward one image frame at a time. |
| 7 | Button to loop the playback. |
| 8 | Slider to move through the sequence file. |
| 9 | Button to access file tools:<br>▪ **Save**<br>▪ **Save as**<br>▪ **Save single image as**<br>▪ **Export** |

# 9.4 Plot window

**Figure**

T630408;a1




**Explanation**

This table explains the figure above:

| | |
|---|---|
| 1 | Temperature scale. |
| 2 | Plot number. |
| 3 | Plot line. You can have several plot lines in the same plot window. In playback mode, the red line indicates the current position in the sequence file. |
| 4 | Close button. |
| 5 | Time scale. |
| 6 | Plot toolbar. |

**NOTE**

Right-clicking the plot lets you do the following:

- Show whole plot.
- Show grid.
- Show legend.
- Export (as pictures or data).
- Copy (as pictures or data).
- Delete the plot.

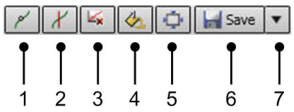
## 9.4.1 Plot window > Plot toolbar

**General**

Diffferent parts of the plot toolbar are displayed in live and playback mode, respectively.

**Figure**

T630422;a2




**Explanation**

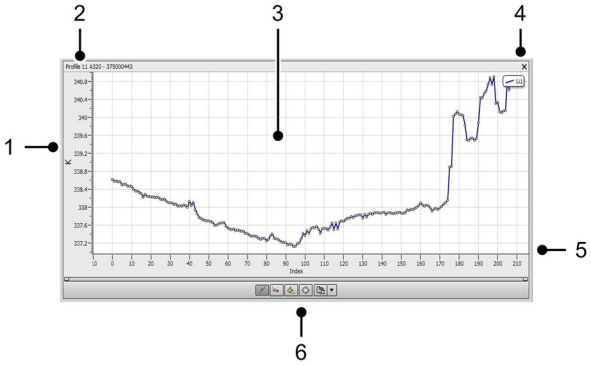
This table explains the figure above:

| | |
|---|---|
| 1 | Button to display markers along the plot line. When you hold the cursor over a marker, the temperature is displayed. |
| 2 | Button to display a cursor along the plot line. |
| 3 | Button to clear the plot window. |
| 4 | Button to change the background color. |
| 5 | Button to show the whole plot. |
| 6 | Button to save the plot in *.plot file format. |
| 7 | Button to access file tools:<br>▪ **Open**<br>▪ **Save**<br>▪ **Save as**<br>▪ **Export**<br>▪ **Copy** |

# 9.5 Profile window

**Figure**

T638292;a1




**Explanation**

This table explains the figure above:

| | |
|---|---|
| 1 | Temperature scale. |
| 2 | Profile number, and the name of the file or image source in use. |
| 3 | Profile line. You can have several profile lines in the same profile window. |
| 4 | Close button. |
| 5 | Index scale. |
| 6 | Profile toolbar. |

**NOTE**

Right-clicking the profile lets you do the following:

- Show whole profile.
- Show grid.
- Show legend.
- Export (as pictures or data).
- Copy (as pictures or data).
- Delete the profile.

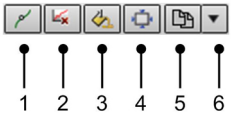
## 9.5.1 Profile window > Profile toolbar

**General**

Diffferent parts of the profile toolbar are displayed in live and playback mode, respectively.

**Figure**

T638297;a1




**Explanation**

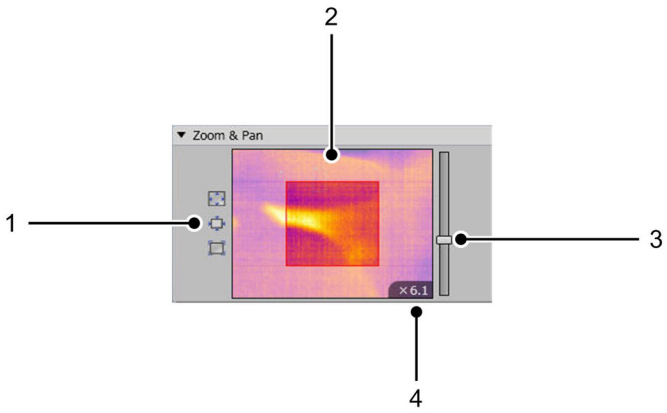
This table explains the figure above:

| | |
|---|---|
| 1 | Button to display markers along the profile line. When you hold the cursor over a marker, the temperature is displayed. |
| 2 | Button to clear the profile window. |
| 3 | Button to change the background color. |
| 4 | Button to show the whole profile. |
| 5 | Button to copy the image |
| 6 | Button to access file tools:<br>▪ **Export**<br>▪ **Copy** |

# 9.6 *Zoom & Pan pane*

**Figure**

T630410;a1




**Explanation**

This table explains the figure above:

| | |
|---|---|
| 1 | Toolbar buttons (from top to bottom):<br>▪ Zoom to fill the window with image.<br>▪ Zoom to fit the image in the window.<br>▪ Zoom to the actual image size (1:1). |
| 2 | Preview window.<br>If you have zoomed into an image, the excluded image area will be displayed in a lighter shade (see the image). You can then move the zoomed-in area over the image using the cursor. |
| 3 | Slider to change the zoom factor. |
| 4 | Zoom factor. |

# 9.7 *Scale pane*

**General**

The scale pane lets you set maximum and minimum temperatures, create isotherms and adjust the image in various ways,

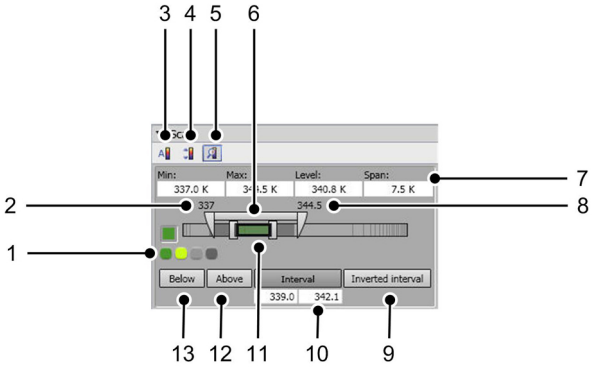
**About isotherms**

An isotherm is a function highlighting those parts of an image that fall above, below, or between one or more temperature intervals. In FLIR R&D software, you can set four different types of isotherms:

- **Interval**: Assigning a color to temperatures between two set temperature levels.
- **Inverted interval**: Assigning a color to temperatures between two set temperature levels, but color-inverted.
- **Above**: Assigning a color to temperatures above a set temperature level.
- **Below**: Assigning a color to temperatures below a set temperature level.

**Figure**

T630411;a7




**Explanation**

This table explains the figure above:

| | |
|---|---|
| 1 | Palette of standard colors that you can use for the isotherms. |
| 2 | Slider to change the lower temperature value. |
| 3 | **Auto** button.<br>You use this button to automatically adjust the image for the best brightness and contrast. |
| 4 | **Reset scale** button.<br>You use this button to reset the scale to auto-adjusted values, i.e. carrying out a one-shot auto-adjust procedure. |
| 5 | **Zoom scale** button.<br>You use this button to zoom into the scale when working with small temperature spans. |

| | |
|---|---|
| 6 | Button to do the following:<br>■ Automatically adjust the image for the best brightness and contrast.<br>■ Change the level (by dragging the button).<br>■ Change the span (by SHIFT-dragging the button). |
| 7 | Text boxes to enter the following:<br>■ **Min**: You use this text box to set specific minimum temperature levels in the image.<br>■ **Max**: You use this text box to set specific maximum temperature levels in the image.<br>■ **Level**: You use this text box to set the temperature level of the image<br>■ **Span**: You use this text box to set the temperature span of the image<br>**Note:** These are four mutually exclusive methods to change the same temperature values. |
| 8 | Slider to change the upper temperature value. |
| 9 | Button to assign a color to temperatures between two set temperature levels, but color-inverted. |
| 10 | Button assign a color to temperatures between two set temperature levels (text boxes diplayed below). |
| 11 | Area in the temperature scale where the defined isotherm color is displayed. |
| 12 | Button to assign a color to temperatures above a set temperature level. |
| 13 | Button to assign a color to temperatures below a set temperature level. |

# 9.8 *Results pane*

**General**

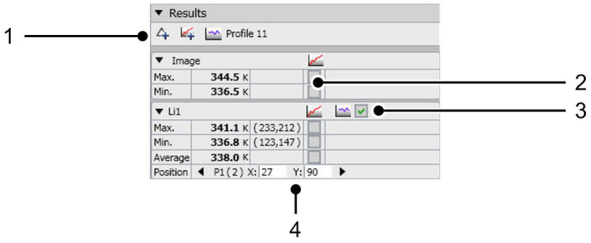
The results pane displays results from measurement tools laid out in the image.

**NOTE**

The figure below shows the results pane when a line has been laid out in the image or sequence file. The results pane will look different when other measurement tools are laid out.

**Figure**

T638293;a1




**Explanation**

This table explains the figure above:

| | |
|---|---|
| 1 | Toolbar buttons for:<br>■ Creating a difference calculation (requires at least two measurement tools previously laid out in the image, or one measurement tool with two different results, such as maximum and minimum temperature).<br>■ Create a plot window on a new tab.<br>■ Create a profile window on a new tab. |
| 2 | Check boxes to enable outputting a plot for this measurement tool in the plot window. |
| 3 | Check boxes to enable outputting a profile for this measurement tool in the profile window. |
| 4 | X and Y position of the measurement tool in question. |

# 10 Recording sequence files

## *10.1 How to set the recording speed*

**General**

Before you start your recording, you need to set the recording speed. The recording speed is the number of frames per second that are saved in the file when you record a sequence.

You can set the recording speed using two different methods:

- Change the camera frame rate.
- Specify a time interval between saved image frames.

**Procedure**

Follow this procedure:

| | |
|---|---|
| 1 | Go to **Analyze** > **Recording**. |
| 2 | Do one of the following:<br>■ Select a new frame rate in the drop-down menu.<br>■ Specify a time interval between saved image frames.<br>In a few seconds you will see how the **Actual frame rate** under **Performance** will be updated to match the changed frame rate. Note that discrepancies may occur for higher frame rates, due to some cameras not being able to deliver that frame rate. |

**NOTE**

For an explanation of screen elements, see section 9 – Overview of screen elements on page 25.

## 10.2 How to set a prerecording

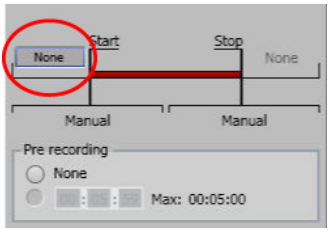
**General**

A prerecording is a defined time interval (of images) that is stored before the actual event that triggers the recording takes place. The image frames in a prerecording are retrieved from a looping image buffer.

In many situations, a prerecording is necessary in order to carry out a successful analysis of the recorded event. A prerecording also provides a full history of the event that triggers the start of the recording.

**Figure**

T630414;a1




**Procedure**

Follow this procedure:

| | |
|---|---|
| 1 | Go to **Analyze** > **Recording**. |
| 2 | Click the encircled button (see the image above). This will display a dialog box where you can define the desired time interval. |

**NOTE**

For an explanation of screen elements, see section 9 – Overview of screen elements on page 25.

## 10.3 How to set a start trigger

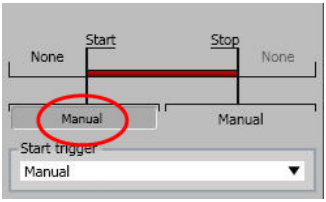
**General**

A start trigger can be regarded as a condition that starts the recording of the event, once the value of the condition is met. In FLIR R&D software you can use the following types of start trigger:

- **Manual**: The recording is started manually.
- **Date & Time**: The recording is started at a set date and time.
- **Conditional**: The recording is started when a measurement value in the image falls above or below a set value. This assumes that you have laid out at least one measurement tool in the image.
- **External trigger**: To let the digital input in FLIR A325 start the recording.

**Figure**

T630420;a1




**Procedure**

Follow this procedure:

| | |
|---|---|
| 1 | Go to **Analyze** > **Recording**. |
| 2 | Click the encircled button (see the image above). This will display a **Start trigger** list box where you can select the desired start trigger type. |
| 3 | (When all start and stop triggers parameters are set.)<br>On the recording toolbar, click **Arm**. This arms the trigger, and the program is now ready to start recording the event once the trigger condition is met. |

**NOTE**

For an explanation of screen elements, see section 9 – Overview of screen elements on page 25.

## 10.4 How to set a stop trigger

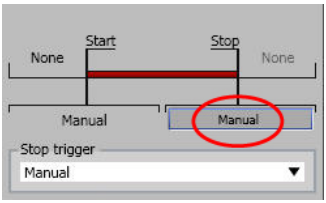
**General**

A stop trigger can be regarded as a condition that stops the recording of the event, once the value of the condition is met. In FLIR R&D software you can use the following types of stop trigger:

- **Manual**: The recording is stopped manually.
- **Date & Time**: The recording is stopped at a set date and time.
- **Duration**: The recording is stopped after a set time has elapsed since the recording was started.
- **Conditional**: The recording is stopped when a measurement value in the image falls above or below a set value. This assumes that you have laid out at least one measurement tool in the image.
- **External trigger**: To let the digital input in FLIR A325 stop the recording.

**Figure**

T630421;a1




**Procedure**

Follow this procedure:

| | |
|---|---|
| 1 | Go to **Analyze** > **Recording**. |
| 2 | Click the encircled button (see the image above). This will display a **Stop trigger** dialog box where you can select the desired start trigger type. |
| 3 | (When all start and stop triggers parameters are set.)<br>On the recording toolbar, click **Arm**. This arms the trigger, and the program is now ready to stop recording the event once the trigger condition is met. |

**NOTE**

For an explanation of screen elements, see section 9 – Overview of screen elements on page 25.

## 10.5 How to set a postrecording

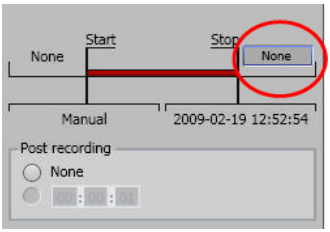
**General**

A postrecording is a defined number of image frames that are stored after the recording that an event has triggered. The image frames in a postrecording are retrieved from a looping image buffer.

In many situations, a postrecording is necessary in order to carry out a successful analysis of the recorded event. A postrecording also provides a full history of the event that triggers the stop of the recording.

**Figure**

T630415;a1




**Procedure**

Follow this procedure:

| | |
|---|---|
| 1 | Go to **Analyze** > **Recording**. |
| 2 | Click the encircled button (see the image above). This will display a dialog box where you can define the desired time interval. |

**NOTE**

- You cannot set a postrecording when the stop trigger is set to **Manual**.
- For an explanation of screen elements, see section 9 – Overview of screen elements on page 25.

# 11 Working with plots

**General**

A temperature plot can be regarded as a graph that displays how the temperatures vary relative to time in a sequence file.

**NOTE**

This procedure assumes that you have connected to a camera and that a live or recorded image is visible in the image window.

**Procedure**

Follow this procedure:

| | |
|---|---|
| 1 | Lay out a measurement tool in the image. |
| 2 | Right-click the measurement tool, select **Plot** and the measurement type that you want to plot (typically max., min., or average temperature). A plot will now be displayed. |
| 3 | At this stage, you may want to do one of the following:<br>▪ Copy the plot as a picture and paste it into a technical report, a white paper, etc.<br>▪ Copy the plot as a *.csv file.<br>▪ Export the plot as a picture.<br>▪ Export the plot as data. |

**NOTE**

- For an explanation of screen elements, see section 9 – Overview of screen elements on page 25.
- For an explanation of how to locate files, see section 8.5 – Locating images or sequence files on page 23.
- For an explanation of how to record a sequence file, see section 10 – Recording sequence files on page 48.
- For an explanation of how export images and data, see section 13 – Exporting data on page 55.

# 12 Working with profiles

**General**

A profile can be regarded as a graph that displays how the temperatures vary relative to a line in an image.

**NOTE**

This procedure assumes that you have connected to a camera and that a live or recorded image is visible in the image window.

**Procedure**

Follow this procedure:

| | |
|---|---|
| 1 | Lay out a measurement line in an image. |
| 2 | Right-click the measurement tool, select **Profile** to create a new profile tab. A profile will now be displayed. |
| 3 | At this stage, you may want to do one of the following:<br>■ Copy the plot as a picture and paste it into a technical report, a white paper, etc.<br>■ Copy the plot as a *.csv file.<br>■ Export the plot as a picture.<br>■ Export the plot as data. |

**NOTE**

- For an explanation of screen elements, see section 9 – Overview of screen elements on page 25.
- For an explanation of how to locate files, see section 8.5 – Locating images or sequence files on page 23.
- For an explanation of how to record a sequence file, see section 10 – Recording sequence files on page 48.
- For an explanation of how export images and data, see section 13 – Exporting data on page 55.

# 13 Exporting data

**General**

You can export image, plot and profile data in various ways. This section described how.

**Exporting image data**

Do one of the following:

- Right-click an image and select **Export** > **Picture**. This will export the current image as a *.bmp file.
- Right-click an image and select **Export** > **Data**. This will export the current image as a *.csv file with an array of temperature value for each pixel.

**Exporting plot data**

Do one of the following:

- Right-click a plot and select **Export** > **Picture**. This will export the current plot as a *.bmp file.
- Right-click a plot and select **Export** > **Data**. This will export the current plot as a *.csv file with the following columns:
  - Date.
  - Time.
  - Milliseconds.
  - Relative time.
  - Average temperature.

**Exporting profile data**

Do one of the following:

- Right-click a profile and select **Export** > **Picture**. This will export the current profile as a *.bmp file.
- Right-click a profile and select **Export** > **Data**. This will export the current profile as an *.csv file with the following columns:
  - Index of markers.
  - Temperatures of markers.

**Exporting sequence data**

Do one of the following:

- Right-click a sequence file and select:
  - **Export** > **Picture**. This will export the current image as a *.bmp file.
  - **Export** > **Single image data**. This will export the current image as a *.csv file with an array of temperature value for each pixel.
  - **Export** > **Sequence data**. This will export the sequence data as a *.csv file.

# 14 Changing settings

## *14.1 Changing program settings*

**General**

You can change a variety of program settings that define output data, temperature units, language, etc.

**Procedure**

Follow this procedure:

| | |
|---|---|
| 1 | On the main menu bar, click **Options**. |
| 2 | Do one of the following:<br>▪ To change the units, click the **Units** tab and do one of the following:<br>  ▪ To change the output data, select **Raw count**, **Object signal**, or **Temperature**.<br>  ▪ To change the temperature unit, select **Celsius**, **Fahrenheit**, or **Kelvin**.<br>▪ To change connection behavior, click the **Application** tab and select **Auto-connect to camera** or **Disable warning message before save**.<br>▪ To change the language, click the **Language** tab and select a new language. |

**Explanation**

- **Raw count**: The pixel value as delivered by the camera on the digital interface or as saved in radiometric image files. No correction for object parameters is included. Depending on the camera model, drift compensation may also not be included.
- **Object signal**: A calibrated value proportional to the radiation from the object. This is the detector signal corrected for drift, gain, and offset, including compensation for object parameters. Correct setting of object parameters (reflected apparent temperature, emissivity, object distance, relative humidity, and atmospheric temperature) is assumed.
- **Temperature**: The blackbody temperature of the object when the calibration algorithm based on Planck's law is applied to the object signal.

# 14.2 Changing object parameters

## 14.2.1 Changing object parameters globally

**General**

For accurate measurements, you must set the object parameters. This procedure describes how to change the object parameters globally.

**Atmospheric parameters group**

- **Atmospheric temperature**: The temperature of the air between the camera and the object of interest.
- **Relative humidity**: The relative humidity of the air between the camera and the object of interest.
- **Transmission**: The computed or fixed transmission through the atmosphere.

**External optics group**

- **Temperature**: The temperature of any protective windows, etc. that are set up between the camera and the object of interest. If no protective window or protective shield is used, this value is irrelevant.
- **Transmission**: The optical transmission of any protective windows, etc., that are set up between the camera and the object of interest.

**Image object parameters group**

- **Emissivity**: How much radiation an object emits, compared with the radiation of a theoretical reference object of the same temperature (called a 'blackbody'). The opposite of emissivity is reflectivity. The emissivity determines how much of the radiation originates from the object as opposed to being reflected by it.
- **Distance**: The distance between the camera and the object of interest.
- **Reflected apparent temperature**: Used when compensating for the radiation from the surroundings reflected by the object into the camera. This property of the object is called reflectivity.

**Procedure**

Follow this procedure:

| | |
|---|---|
| 1 | Go to the **Parameters** pane. |
| 2 | Put the cursor in the white text box to the right of the parameter that you want to change. |
| 3 | Type the new value and press the RETURN key. |

**Related topics**

For in-depth information about parameters, and how to correctly set the emissivity and reflected apparent temperature, see section 17 – Thermographic measurement techniques on page 67.

## 14.2.2 Changing object parameters locally

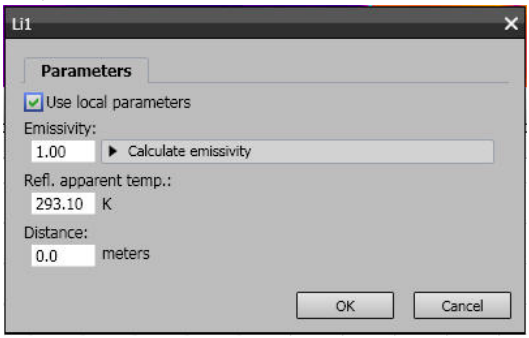
**General**

When you change object parameters, all object parameters for the whole image are changed.

However, in some situations you only want to change an object parameter for one measurement tool only. The reason for this may be that the measurement tool is in front of a significantly more reflective surface than other surfaces in the image, or over an object that is further away than the rest of the objects in the image, and so on.

**Procedure**

Follow this procedure:

| | |
|---|---|
| 1 | Place at least one measurement tool in the image. |
| 2 | Right-click the tool and select **Parameters**. This will display the following dialog box.<br>T638028;a3<br>  |
| 3 | Select **Use local parameters**. |
| 4 | Do one of the following:<br>▪ Let the program calculate the emissivity. This requires knowledge of the temperature of the object in question.<br>▪ Enter a known value for the reflected apparent temperature.<br>▪ Enter a known value for the distance to the object. |

**NOTE**

- You can also change an object parameter locally by right-clicking the measurement result in the results pane.
- Using the emissivity calculator requires that **Data output** is set to Kelvin, Celsius or Fahrenheit under **Options**.

**Related topics**

For in-depth information about parameters, and how to correctly set the emissivity and reflected apparent temperature, see section 17 – Thermographic measurement techniques on page 67.

# 15 About FLIR Systems

FLIR Systems was established in 1978 to pioneer the development of high-performance infrared imaging systems, and is the world leader in the design, manufacture, and marketing of thermal imaging systems for a wide variety of commercial, industrial, and government applications. Today, FLIR Systems embraces five major companies with outstanding achievements in infrared technology since 1958—the Swedish AGEMA Infrared Systems (formerly AGA Infrared Systems), the three United States companies Indigo Systems, FSI, and Inframetrics, and the French company Cedip. In November 2007, Extech Instruments was acquired by FLIR Systems.

10722703;a2

**Figure 15.1 LEFT:** Thermovision® Model 661 from 1969. The camera weighed approximately 25 kg (55 lb.), the oscilloscope 20 kg (44 lb.), and the tripod 15 kg (33 lb.). The operator also needed a 220 VAC generator set, and a 10 L (2.6 US gallon) jar with liquid nitrogen. To the left of the oscilloscope the Polaroid attachment (6 kg/13 lb.) can be seen. **RIGHT:** FLIR i7 from 2009. Weight: 0.34 kg (0.75 lb.), including the battery.

The company has sold more than 100,000 infrared cameras worldwide for applications such as predictive maintenance, R & D, non-destructive testing, process control and automation, and machine vision, among many others.

FLIR Systems has three manufacturing plants in the United States (Portland, OR, Boston, MA, Santa Barbara, CA) and one in Sweden (Stockholm). Since 2007 there is also a manufacturing plant in Tallinn, Estonia. Direct sales offices in Belgium, Brazil, China, France, Germany, Great Britain, Hong Kong, Italy, Japan, Korea, Sweden, and the USA—together with a worldwide network of agents and distributors—support our international customer base.

FLIR Systems is at the forefront of innovation in the infrared camera industry. We anticipate market demand by constantly improving our existing cameras and developing new ones. The company has set milestones in product design and development such as the introduction of the first battery-operated portable camera for industrial inspections, and the first uncooled infrared camera, to mention just two innovations.

FLIR Systems manufactures all vital mechanical and electronic components of the camera systems itself. From detector design and manufacturing, to lenses and system electronics, to final testing and calibration, all production steps are carried out and supervised by our own engineers. The in-depth expertise of these infrared specialists ensures the accuracy and reliability of all vital components that are assembled into your infrared camera.

## *15.1 More than just an infrared camera*

At FLIR Systems we recognize that our job is to go beyond just producing the best infrared camera systems. We are committed to enabling all users of our infrared camera systems to work more productively by providing them with the most powerful camera–software combination. Especially tailored software for predictive maintenance, R & D, and process monitoring is developed in-house. Most software is available in a wide variety of languages.

We support all our infrared cameras with a wide variety of accessories to adapt your equipment to the most demanding infrared applications.

## *15.2 Sharing our knowledge*

Although our cameras are designed to be very user-friendly, there is a lot more to thermography than just knowing how to handle a camera. Therefore, FLIR Systems has founded the Infrared Training Center (ITC), a separate business unit, that provides certified training courses. Attending one of the ITC courses will give you a truly hands-on learning experience.

The staff of the ITC are also there to provide you with any application support you may need in putting infrared theory into practice.

## *15.3 Supporting our customers*

FLIR Systems operates a worldwide service network to keep your camera running at all times. If you discover a problem with your camera, local service centers have all the equipment and expertise to solve it within the shortest possible time. Therefore, there is no need to send your camera to the other side of the world or to talk to someone who does not speak your language.

## 15.4 A few images from our facilities

10401303;a1

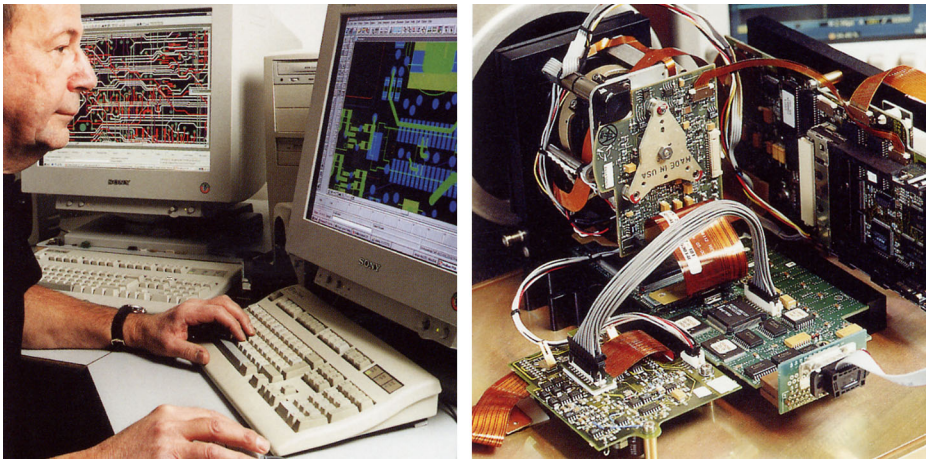


**Figure 15.2 LEFT:** Development of system electronics; **RIGHT:** Testing of an FPA detector

10401403;a1

**Figure 15.3 LEFT:** Diamond turning machine; **RIGHT:** Lens polishing

10401503;a1

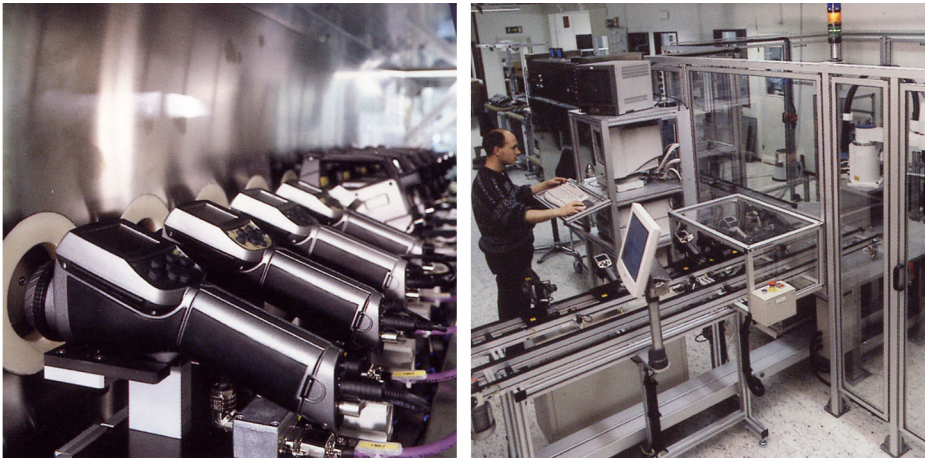


**Figure 15.4 LEFT:** Testing of infrared cameras in the climatic chamber; **RIGHT:** Robot used for camera testing and calibration

# 16 Glossary

| Term or expression | Explanation |
|---|---|
| absorption (absorption factor) | The amount of radiation absorbed by an object relative to the received radiation. A number between 0 and 1. |
| atmosphere | The gases between the object being measured and the camera, normally air. |
| autoadjust | A function making a camera perform an internal image correction. |
| autopalette | The IR image is shown with an uneven spread of colors, displaying cold objects as well as hot ones at the same time. |
| blackbody | Totally non-reflective object. All its radiation is due to its own temperature. |
| blackbody radiator | An IR radiating equipment with blackbody properties used to calibrate IR cameras. |
| calculated atmospheric transmission | A transmission value computed from the temperature, the relative humidity of air and the distance to the object. |
| cavity radiator | A bottle shaped radiator with an absorbing inside, viewed through the bottleneck. |
| color temperature | The temperature for which the color of a blackbody matches a specific color. |
| conduction | The process that makes heat diffuse into a material. |
| continuous adjust | A function that adjusts the image. The function works all the time, continuously adjusting brightness and contrast according to the image content. |
| convection | Convection is a heat transfer mode where a fluid is brought into motion, either by gravity or another force, thereby transferring heat from one place to another. |
| dual isotherm | An isotherm with two color bands, instead of one. |
| emissivity (emissivity factor) | The amount of radiation coming from an object, compared to that of a blackbody. A number between 0 and 1. |
| emittance | Amount of energy emitted from an object per unit of time and area ($W/m^2$) |
| environment | Objects and gases that emit radiation towards the object being measured. |
| estimated atmospheric transmission | A transmission value, supplied by a user, replacing a calculated one |

| Term or expression | Explanation |
|---|---|
| external optics | Extra lenses, filters, heat shields etc. that can be put between the camera and the object being measured. |
| filter | A material transparent only to some of the infrared wavelengths. |
| FOV | Field of view: The horizontal angle that can be viewed through an IR lens. |
| FPA | Focal plane array: A type of IR detector. |
| graybody | An object that emits a fixed fraction of the amount of energy of a blackbody for each wavelength. |
| IFOV | Instantaneous field of view: A measure of the geometrical resolution of an IR camera. |
| image correction (internal or external) | A way of compensating for sensitivity differences in various parts of live images and also of stabilizing the camera. |
| infrared | Non-visible radiation, having a wavelength from about 2–13 µm. |
| IR | infrared |
| isotherm | A function highlighting those parts of an image that fall above, below or between one or more temperature intervals. |
| isothermal cavity | A bottle-shaped radiator with a uniform temperature viewed through the bottleneck. |
| Laser LocatIR | An electrically powered light source on the camera that emits laser radiation in a thin, concentrated beam to point at certain parts of the object in front of the camera. |
| laser pointer | An electrically powered light source on the camera that emits laser radiation in a thin, concentrated beam to point at certain parts of the object in front of the camera. |
| level | The center value of the temperature scale, usually expressed as a signal value. |
| manual adjust | A way to adjust the image by manually changing certain parameters. |
| NETD | Noise equivalent temperature difference. A measure of the image noise level of an IR camera. |
| noise | Undesired small disturbance in the infrared image |
| object parameters | A set of values describing the circumstances under which the measurement of an object was made, and the object itself (such as emissivity, reflected apparent temperature, distance etc.) |
| object signal | A non-calibrated value related to the amount of radiation received by the camera from the object. |

| Term or expression | Explanation |
|---|---|
| palette | The set of colors used to display an IR image. |
| pixel | Stands for *picture element*. One single spot in an image. |
| radiance | Amount of energy emitted from an object per unit of time, area and angle ($W/m^2/sr$) |
| radiant power | Amount of energy emitted from an object per unit of time (W) |
| radiation | The process by which electromagnetic energy, is emitted by an object or a gas. |
| radiator | A piece of IR radiating equipment. |
| range | The current overall temperature measurement limitation of an IR camera. Cameras can have several ranges. Expressed as two blackbody temperatures that limit the current calibration. |
| reference temperature | A temperature which the ordinary measured values can be compared with. |
| reflection | The amount of radiation reflected by an object relative to the received radiation. A number between 0 and 1. |
| relative humidity | Relative humidity represents the ratio between the current water vapour mass in the air and the maximum it may contain in saturation conditions. |
| saturation color | The areas that contain temperatures outside the present level/span settings are colored with the saturation colors. The saturation colors contain an 'overflow' color and an 'underflow' color. There is also a third red saturation color that marks everything saturated by the detector indicating that the range should probably be changed. |
| span | The interval of the temperature scale, usually expressed as a signal value. |
| spectral (radiant) emittance | Amount of energy emitted from an object per unit of time, area and wavelength ($W/m^2/\mu m$) |
| temperature difference, or difference of temperature. | A value which is the result of a subtraction between two temperature values. |
| temperature range | The current overall temperature measurement limitation of an IR camera. Cameras can have several ranges. Expressed as two blackbody temperatures that limit the current calibration. |
| temperature scale | The way in which an IR image currently is displayed. Expressed as two temperature values limiting the colors. |
| thermogram | infrared image |

| Term or expression | Explanation |
|---|---|
| transmission (or transmittance) factor | Gases and materials can be more or less transparent. Transmission is the amount of IR radiation passing through them. A number between 0 and 1. |
| transparent isotherm | An isotherm showing a linear spread of colors, instead of covering the highlighted parts of the image. |
| visual | Refers to the video mode of a IR camera, as opposed to the normal, thermographic mode. When a camera is in video mode it captures ordinary video images, while thermographic images are captured when the camera is in IR mode. |

# 17 Thermographic measurement techniques

## *17.1 Introduction*

An infrared camera measures and images the emitted infrared radiation from an object. The fact that radiation is a function of object surface temperature makes it possible for the camera to calculate and display this temperature.

However, the radiation measured by the camera does not only depend on the temperature of the object but is also a function of the emissivity. Radiation also originates from the surroundings and is reflected in the object. The radiation from the object and the reflected radiation will also be influenced by the absorption of the atmosphere.

To measure temperature accurately, it is therefore necessary to compensate for the effects of a number of different radiation sources. This is done on-line automatically by the camera. The following object parameters must, however, be supplied for the camera:

- The emissivity of the object
- The reflected apparent temperature
- The distance between the object and the camera
- The relative humidity
- Temperature of the atmosphere

## *17.2 Emissivity*

The most important object parameter to set correctly is the emissivity which, in short, is a measure of how much radiation is emitted from the object, compared to that from a perfect blackbody of the same temperature.

Normally, object materials and surface treatments exhibit emissivity ranging from approximately 0.1 to 0.95. A highly polished (mirror) surface falls below 0.1, while an oxidized or painted surface has a higher emissivity. Oil-based paint, regardless of color in the visible spectrum, has an emissivity over 0.9 in the infrared. Human skin exhibits an emissivity 0.97 to 0.98.

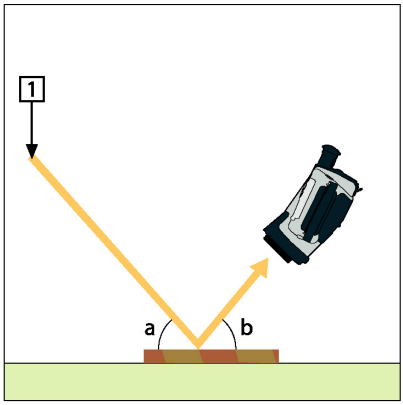
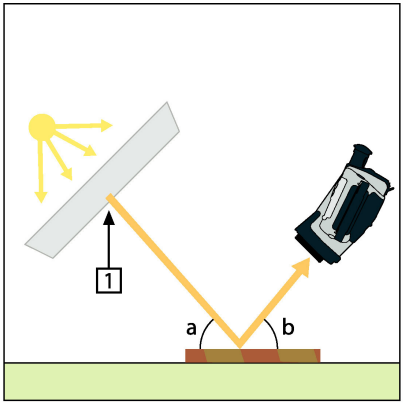
Non-oxidized metals represent an extreme case of perfect opacity and high reflexivity, which does not vary greatly with wavelength. Consequently, the emissivity of metals is low – only increasing with temperature. For non-metals, emissivity tends to be high, and decreases with temperature.

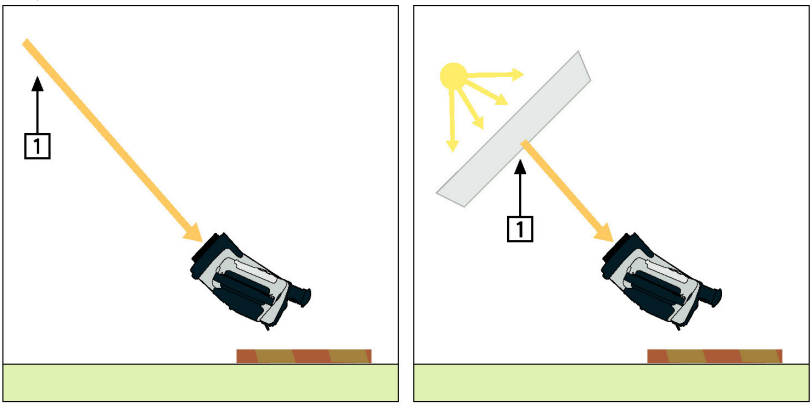
## 17.2.1 Finding the emissivity of a sample

### *17.2.1.1 Step 1: Determining reflected apparent temperature*

Use one of the following two methods to determine reflected apparent temperature:

#### *17.2.1.1.1 Method 1: Direct method*

| | |
|---|---|
| **1** | Look for possible reflection sources, considering that the incident angle = reflection angle (a = b).<br>10588903;a1<br>  <br><br>**Figure 17.1** 1 = Reflection source |
| **2** | If the reflection source is a spot source, modify the source by obstructing it using a piece if cardboard.<br>10589103;a2<br>  <br><br>**Figure 17.2** 1 = Reflection source |

| | |
|---|---|
| **3** | Measure the radiation intensity (= apparent temperature) from the reflecting source using the following settings:<br>▪ Emissivity: 1.0<br>▪ $D_{obj}$: 0<br>You can measure the radiation intensity using one of the following two methods:<br>10589003;a2<br>  <br>**Figure 17.3** 1 = Reflection source |

**Note:** Using a thermocouple to measure reflected apparent temperature is not recommended for two important reasons:

- A thermocouple does not measure radiation intensity
- A thermocouple requires a very good thermal contact to the surface, usually by gluing and covering the sensor by a thermal isolator.

### *17.2.1.1.2 Method 2: Reflector method*

| | |
|---|---|
| **1** | Crumble up a large piece of aluminum foil. |
| **2** | Uncrumble the aluminum foil and attach it to a piece of cardboard of the same size. |
| **3** | Put the piece of cardboard in front of the object you want to measure. Make sure that the side with aluminum foil points to the camera. |
| **4** | Set the emissivity to 1.0. |

| | |
|---|---|
| **5** | Measure the apparent temperature of the aluminum foil and write it down. |

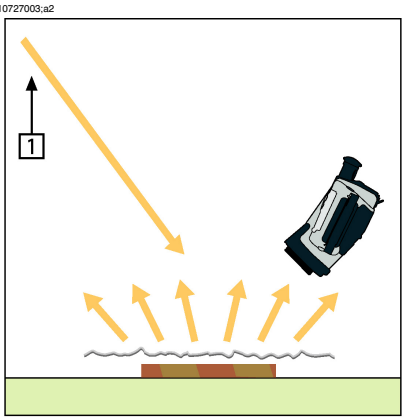



**Figure 17.4** Measuring the apparent temperature of the aluminum foil

### *17.2.1.2 Step 2: Determining the emissivity*

| | |
|---|---|
| **1** | Select a place to put the sample. |
| **2** | Determine and set reflected apparent temperature according to the previous procedure. |
| **3** | Put a piece of electrical tape with known high emissivity on the sample. |
| **4** | Heat the sample at least 20 K above room temperature. Heating must be reasonably even. |
| **5** | Focus and auto-adjust the camera, and freeze the image. |
| **6** | Adjust **Level** and **Span** for best image brightness and contrast. |
| **7** | Set emissivity to that of the tape (usually 0.97). |
| **8** | Measure the temperature of the tape using one of the following measurement functions:<br>▪ **Isotherm** (helps you to determine both the temperature and how evenly you have heated the sample)<br>▪ **Spot** (simpler)<br>▪ **Box Avg** (good for surfaces with varying emissivity). |
| **9** | Write down the temperature. |
| **10** | Move your measurement function to the sample surface. |
| **11** | Change the emissivity setting until you read the same temperature as your previous measurement. |
| **12** | Write down the emissivity. |

**Note:**

- Avoid forced convection
- Look for a thermally stable surrounding that will not generate spot reflections
- Use high quality tape that you know is not transparent, and has a high emissivity you are certain of
- This method assumes that the temperature of your tape and the sample surface are the same. If they are not, your emissivity measurement will be wrong.

## *17.3 Reflected apparent temperature*

This parameter is used to compensate for the radiation reflected in the object. If the emissivity is low and the object temperature relatively far from that of the reflected it will be important to set and compensate for the reflected apparent temperature correctly.

## *17.4 Distance*

The distance is the distance between the object and the front lens of the camera. This parameter is used to compensate for the following two facts:

- That radiation from the target is absorbed by the athmosphere between the object and the camera.
- That radiation from the atmosphere itself is detected by the camera.

## *17.5 Relative humidity*

The camera can also compensate for the fact that the transmittance is also dependent on the relative humidity of the atmosphere. To do this set the relative humidity to the correct value. For short distances and normal humidity the relative humidity can normally be left at a default value of 50%.

## *17.6 Other parameters*

In addition, some cameras and analysis programs from FLIR Systems allow you to compensate for the following parameters:

- Atmospheric temperature – *i.e.* the temperature of the atmosphere between the camera and the target
- External optics temperature – *i.e.* the temperature of any external lenses or windows used in front of the camera
- External optics transmittance – *i.e.* the transmission of any external lenses or windows used in front of the camera

# 18 History of infrared technology

Before the year 1800, the existence of the infrared portion of the electromagnetic spectrum wasn't even suspected. The original significance of the infrared spectrum, or simply ‘the infrared’ as it is often called, as a form of heat radiation is perhaps less obvious today than it was at the time of its discovery by Herschel in 1800.

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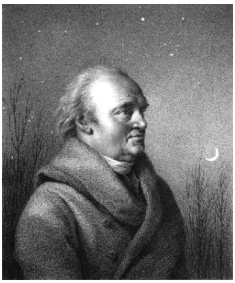

**Figure 18.1** Sir William Herschel (1738–1822)

The discovery was made accidentally during the search for a new optical material. Sir William Herschel – Royal Astronomer to King George III of England, and already famous for his discovery of the planet Uranus – was searching for an optical filter material to reduce the brightness of the sun’s image in telescopes during solar observations. While testing different samples of colored glass which gave similar reductions in brightness he was intrigued to find that some of the samples passed very little of the sun’s heat, while others passed so much heat that he risked eye damage after only a few seconds’ observation.

Herschel was soon convinced of the necessity of setting up a systematic experiment, with the objective of finding a single material that would give the desired reduction in brightness as well as the maximum reduction in heat. He began the experiment by actually repeating Newton’s prism experiment, but looking for the heating effect rather than the visual distribution of intensity in the spectrum. He first blackened the bulb of a sensitive mercury-in-glass thermometer with ink, and with this as his radiation detector he proceeded to test the heating effect of the various colors of the spectrum formed on the top of a table by passing sunlight through a glass prism. Other thermometers, placed outside the sun’s rays, served as controls.

As the blackened thermometer was moved slowly along the colors of the spectrum, the temperature readings showed a steady increase from the violet end to the red end. This was not entirely unexpected, since the Italian researcher, Landriani, in a similar experiment in 1777 had observed much the same effect. It was Herschel,

however, who was the first to recognize that there must be a point where the heating effect reaches a maximum, and that measurements confined to the visible portion of the spectrum failed to locate this point.

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**Figure 18.2** Marsilio Landriani (1746–1815)

Moving the thermometer into the dark region beyond the red end of the spectrum, Herschel confirmed that the heating continued to increase. The maximum point, when he found it, lay well beyond the red end – in what is known today as the 'infrared wavelengths'.

When Herschel revealed his discovery, he referred to this new portion of the electromagnetic spectrum as the 'thermometrical spectrum'. The radiation itself he sometimes referred to as 'dark heat', or simply 'the invisible rays'. Ironically, and contrary to popular opinion, it wasn't Herschel who originated the term 'infrared'. The word only began to appear in print around 75 years later, and it is still unclear who should receive credit as the originator.

Herschel's use of glass in the prism of his original experiment led to some early controversies with his contemporaries about the actual existence of the infrared wavelengths. Different investigators, in attempting to confirm his work, used various types of glass indiscriminately, having different transparencies in the infrared. Through his later experiments, Herschel was aware of the limited transparency of glass to the newly-discovered thermal radiation, and he was forced to conclude that optics for the infrared would probably be doomed to the use of reflective elements exclusively (i.e. plane and curved mirrors). Fortunately, this proved to be true only until 1830, when the Italian investigator, Melloni, made his great discovery that naturally occurring rock salt (NaCl) – which was available in large enough natural crystals to be made into lenses and prisms – is remarkably transparent to the infrared. The result was that rock salt became the principal infrared optical material, and remained so for the next hundred years, until the art of synthetic crystal growing was mastered in the 1930's.

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**Figure 18.3** Macedonio Melloni (1798–1854)

Thermometers, as radiation detectors, remained unchallenged until 1829, the year Nobili invented the thermocouple. (Herschel's own thermometer could be read to 0.2 °C (0.036 °F), and later models were able to be read to 0.05 °C (0.09 °F)). Then a breakthrough occurred; Melloni connected a number of thermocouples in series to form the first thermopile. The new device was at least 40 times as sensitive as the best thermometer of the day for detecting heat radiation – capable of detecting the heat from a person standing three meters away.

The first so-called 'heat-picture' became possible in 1840, the result of work by Sir John Herschel, son of the discoverer of the infrared and a famous astronomer in his own right. Based upon the differential evaporation of a thin film of oil when exposed to a heat pattern focused upon it, the thermal image could be seen by reflected light where the interference effects of the oil film made the image visible to the eye. Sir John also managed to obtain a primitive record of the thermal image on paper, which he called a 'thermograph'.

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**Figure 18.4** Samuel P. Langley (1834–1906)

The improvement of infrared-detector sensitivity progressed slowly. Another major breakthrough, made by Langley in 1880, was the invention of the bolometer. This consisted of a thin blackened strip of platinum connected in one arm of a Wheatstone bridge circuit upon which the infrared radiation was focused and to which a sensitive galvanometer responded. This instrument is said to have been able to detect the heat from a cow at a distance of 400 meters.

An English scientist, Sir James Dewar, first introduced the use of liquefied gases as cooling agents (such as liquid nitrogen with a temperature of -196 °C (-320.8 °F)) in low temperature research. In 1892 he invented a unique vacuum insulating container in which it is possible to store liquefied gases for entire days. The common 'thermos bottle', used for storing hot and cold drinks, is based upon his invention.

Between the years 1900 and 1920, the inventors of the world 'discovered' the infrared. Many patents were issued for devices to detect personnel, artillery, aircraft, ships – and even icebergs. The first operating systems, in the modern sense, began to be developed during the 1914–18 war, when both sides had research programs devoted to the military exploitation of the infrared. These programs included experimental systems for enemy intrusion/detection, remote temperature sensing, secure communications, and 'flying torpedo' guidance. An infrared search system tested during this period was able to detect an approaching airplane at a distance of 1.5 km (0.94 miles), or a person more than 300 meters (984 ft.) away.

The most sensitive systems up to this time were all based upon variations of the bolometer idea, but the period between the two wars saw the development of two revolutionary new infrared detectors: the image converter and the photon detector. At first, the image converter received the greatest attention by the military, because it enabled an observer for the first time in history to literally 'see in the dark'. However, the sensitivity of the image converter was limited to the near infrared wavelengths, and the most interesting military targets (i.e. enemy soldiers) had to be illuminated by infrared search beams. Since this involved the risk of giving away the observer's position to a similarly-equipped enemy observer, it is understandable that military interest in the image converter eventually faded.

The tactical military disadvantages of so-called 'active' (i.e. search beam-equipped) thermal imaging systems provided impetus following the 1939–45 war for extensive secret military infrared-research programs into the possibilities of developing 'passive' (no search beam) systems around the extremely sensitive photon detector. During this period, military secrecy regulations completely prevented disclosure of the status of infrared-imaging technology. This secrecy only began to be lifted in the middle of the 1950's, and from that time adequate thermal-imaging devices finally began to be available to civilian science and industry.

# 19 Theory of thermography

## *19.1 Introduction*

The subjects of infrared radiation and the related technique of thermography are still new to many who will use an infrared camera. In this section the theory behind thermography will be given.

## *19.2 The electromagnetic spectrum*

The electromagnetic spectrum is divided arbitrarily into a number of wavelength regions, called *bands*, distinguished by the methods used to produce and detect the radiation. There is no fundamental difference between radiation in the different bands of the electromagnetic spectrum. They are all governed by the same laws and the only differences are those due to differences in wavelength.

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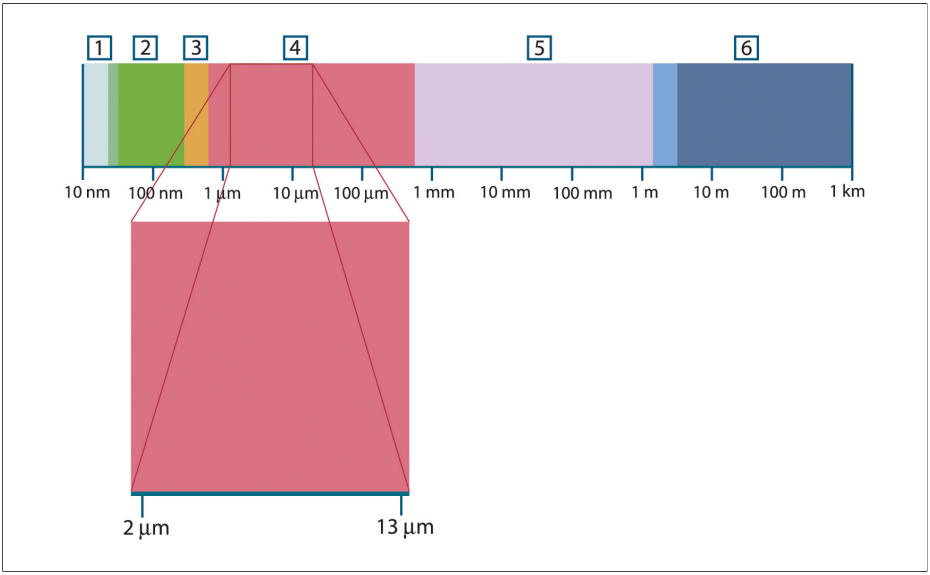


**Figure 19.1** The electromagnetic spectrum. **1:** X-ray; **2:** UV; **3:** Visible; **4:** IR; **5:** Microwaves; **6:** Radiowaves.

Thermography makes use of the infrared spectral band. At the short-wavelength end the boundary lies at the limit of visual perception, in the deep red. At the long-wavelength end it merges with the microwave radio wavelengths, in the millimeter range.

The infrared band is often further subdivided into four smaller bands, the boundaries of which are also arbitrarily chosen. They include: the *near infrared* (0.75–3 µm), the *middle infrared* (3–6 µm), the *far infrared* (6–15 µm) and the *extreme infrared* (15–100

µm). Although the wavelengths are given in µm (micrometers), other units are often still used to measure wavelength in this spectral region, *e.g.* nanometer (nm) and Ångström (Å).

The relationships between the different wavelength measurements is:

$$10\ 000\ \text{Å} = 1\ 000\ \text{nm} = 1\ \mu = 1\ \mu\text{m}$$

## 19.3 Blackbody radiation

A blackbody is defined as an object which absorbs all radiation that impinges on it at any wavelength. The apparent misnomer *black* relating to an object emitting radiation is explained by Kirchhoff's Law (after *Gustav Robert Kirchhoff*, 1824–1887), which states that a body capable of absorbing all radiation at any wavelength is equally capable in the emission of radiation.

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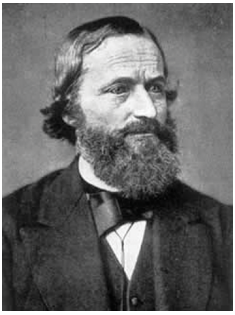

**Figure 19.2** Gustav Robert Kirchhoff (1824–1887)

The construction of a blackbody source is, in principle, very simple. The radiation characteristics of an aperture in an isotherm cavity made of an opaque absorbing material represents almost exactly the properties of a blackbody. A practical application of the principle to the construction of a perfect absorber of radiation consists of a box that is light tight except for an aperture in one of the sides. Any radiation which then enters the hole is scattered and absorbed by repeated reflections so only an infinitesimal fraction can possibly escape. The blackness which is obtained at the aperture is nearly equal to a blackbody and almost perfect for all wavelengths.

By providing such an isothermal cavity with a suitable heater it becomes what is termed a *cavity radiator*. An isothermal cavity heated to a uniform temperature generates blackbody radiation, the characteristics of which are determined solely by the temperature of the cavity. Such cavity radiators are commonly used as sources of radiation in temperature reference standards in the laboratory for calibrating thermographic instruments, such as a FLIR Systems camera for example.

If the temperature of blackbody radiation increases to more than 525°C (977°F), the source begins to be visible so that it appears to the eye no longer black. This is the incipient red heat temperature of the radiator, which then becomes orange or yellow as the temperature increases further. In fact, the definition of the so-called *color temperature* of an object is the temperature to which a blackbody would have to be heated to have the same appearance.

Now consider three expressions that describe the radiation emitted from a blackbody.

### 19.3.1 Planck's law

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**Figure 19.3** Max Planck (1858–1947)

*Max Planck* (1858–1947) was able to describe the spectral distribution of the radiation from a blackbody by means of the following formula:

$$W_{\lambda b} = \frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT} - 1\right)} \times 10^{-6}[Watt/m^2, \mu m]$$

where:

| | |
|---|---|
| $W_{\lambda b}$ | Blackbody spectral radiant emittance at wavelength λ. |
| c | Velocity of light = $3 \times 10^8$ m/s |
| h | Planck's constant = $6.6 \times 10^{-34}$ Joule sec. |
| k | Boltzmann's constant = $1.4 \times 10^{-23}$ Joule/K. |
| T | Absolute temperature (K) of a blackbody. |
| λ | Wavelength (μm). |

➲ The factor $10^{-6}$ is used since spectral emittance in the curves is expressed in Watt/$m^2$, µm.

Planck's formula, when plotted graphically for various temperatures, produces a family of curves. Following any particular Planck curve, the spectral emittance is zero at $\lambda = 0$, then increases rapidly to a maximum at a wavelength $\lambda_{max}$ and after passing it approaches zero again at very long wavelengths. The higher the temperature, the shorter the wavelength at which maximum occurs.

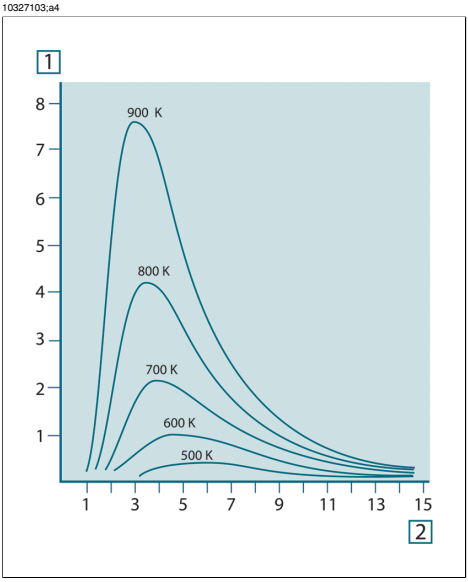


**Figure 19.4** Blackbody spectral radiant emittance according to Planck's law, plotted for various absolute temperatures. **1:** Spectral radiant emittance (W/$cm^2$ × $10^3$(µm)); **2:** Wavelength (µm)

### 19.3.2 Wien's displacement law

By differentiating Planck's formula with respect to λ, and finding the maximum, we have:

$$\lambda_{\max} = \frac{2898}{T}[\mu m]$$

This is Wien's formula (after *Wilhelm Wien*, 1864–1928), which expresses mathematically the common observation that colors vary from red to orange or yellow as the temperature of a thermal radiator increases. The wavelength of the color is the same as the wavelength calculated for $\lambda_{max}$. A good approximation of the value of $\lambda_{max}$ for a given blackbody temperature is obtained by applying the rule-of-thumb 3 000/T

µm. Thus, a very hot star such as Sirius (11 000 K), emitting bluish-white light, radiates with the peak of spectral radiant emittance occurring within the invisible ultraviolet spectrum, at wavelength 0.27 µm.

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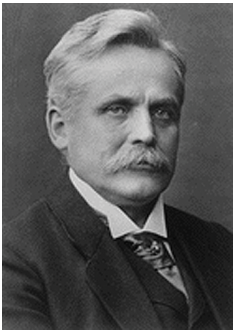

**Figure 19.5** Wilhelm Wien (1864–1928)

The sun (approx. 6 000 K) emits yellow light, peaking at about 0.5 µm in the middle of the visible light spectrum.

At room temperature (300 K) the peak of radiant emittance lies at 9.7 µm, in the far infrared, while at the temperature of liquid nitrogen (77 K) the maximum of the almost insignificant amount of radiant emittance occurs at 38 µm, in the extreme infrared wavelengths.

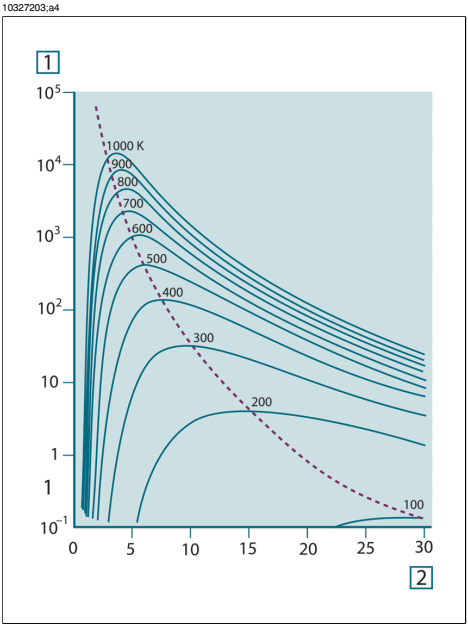


**Figure 19.6** Planckian curves plotted on semi-log scales from 100 K to 1000 K. The dotted line represents the locus of maximum radiant emittance at each temperature as described by Wien's displacement law. **1:** Spectral radiant emittance (W/cm$^2$ (µm)); **2:** Wavelength (µm).

### 19.3.3 Stefan-Boltzmann's law

By integrating Planck's formula from $\lambda = 0$ to $\lambda = \infty$, we obtain the total radiant emittance ($W_b$) of a blackbody:

$$W_b = \sigma T^4 \ [\mathrm{Watt/m^2}]$$

This is the Stefan-Boltzmann formula (after *Josef Stefan*, 1835–1893, and *Ludwig Boltzmann*, 1844–1906), which states that the total emissive power of a blackbody is proportional to the fourth power of its absolute temperature. Graphically, $W_b$ represents the area below the Planck curve for a particular temperature. It can be shown that the radiant emittance in the interval $\lambda = 0$ to $\lambda_{max}$ is only 25% of the total, which represents about the amount of the sun's radiation which lies inside the visible light spectrum.

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**Figure 19.7** Josef Stefan (1835–1893), and Ludwig Boltzmann (1844–1906)

Using the Stefan-Boltzmann formula to calculate the power radiated by the human body, at a temperature of 300 K and an external surface area of approx. 2 $m^2$, we obtain 1 kW. This power loss could not be sustained if it were not for the compensating absorption of radiation from surrounding surfaces, at room temperatures which do not vary too drastically from the temperature of the body – or, of course, the addition of clothing.

### 19.3.4 Non-blackbody emitters

So far, only blackbody radiators and blackbody radiation have been discussed. However, real objects almost never comply with these laws over an extended wavelength region – although they may approach the blackbody behavior in certain spectral intervals. For example, a certain type of white paint may appear perfectly *white* in the visible light spectrum, but becomes distinctly *gray* at about 2 µm, and beyond 3 µm it is almost *black*.

There are three processes which can occur that prevent a real object from acting like a blackbody: a fraction of the incident radiation α may be absorbed, a fraction ρ may be reflected, and a fraction τ may be transmitted. Since all of these factors are more or less wavelength dependent, the subscript λ is used to imply the spectral dependence of their definitions. Thus:

- The spectral absorptance $\alpha_\lambda$ = the ratio of the spectral radiant power absorbed by an object to that incident upon it.
- The spectral reflectance $\rho_\lambda$ = the ratio of the spectral radiant power reflected by an object to that incident upon it.
- The spectral transmittance $\tau_\lambda$ = the ratio of the spectral radiant power transmitted through an object to that incident upon it.

The sum of these three factors must always add up to the whole at any wavelength, so we have the relation:

$$\alpha_\lambda + \rho_\lambda + \tau_\lambda = 1$$

For opaque materials $\tau_\lambda = 0$ and the relation simplifies to:

$$\alpha_\lambda + \rho_\lambda = 1$$

Another factor, called the emissivity, is required to describe the fraction ε of the radiant emittance of a blackbody produced by an object at a specific temperature. Thus, we have the definition:

The spectral emissivity $\varepsilon_\lambda$= the ratio of the spectral radiant power from an object to that from a blackbody at the same temperature and wavelength.

Expressed mathematically, this can be written as the ratio of the spectral emittance of the object to that of a blackbody as follows:

$$\varepsilon_\lambda = \frac{W_{\lambda o}}{W_{\lambda b}}$$

Generally speaking, there are three types of radiation source, distinguished by the ways in which the spectral emittance of each varies with wavelength.

- A blackbody, for which $\varepsilon_\lambda = \varepsilon = 1$
- A graybody, for which $\varepsilon_\lambda = \varepsilon$ = constant less than 1
- A selective radiator, for which ε varies with wavelength

According to Kirchhoff's law, for any material the spectral emissivity and spectral absorptance of a body are equal at any specified temperature and wavelength. That is:

$$\varepsilon_\lambda = \alpha_\lambda$$

From this we obtain, for an opaque material (since $\alpha_\lambda + \rho_\lambda = 1$):

$$\varepsilon_\lambda + \rho_\lambda = 1$$

For highly polished materials $\varepsilon_\lambda$ approaches zero, so that for a perfectly reflecting material (*i.e.* a perfect mirror) we have:

$$\rho_\lambda = 1$$

For a graybody radiator, the Stefan-Boltzmann formula becomes:

$$W = \varepsilon \sigma T^4 \, [\mathrm{Watt/m^2}]$$

This states that the total emissive power of a graybody is the same as a blackbody at the same temperature reduced in proportion to the value of ε from the graybody.

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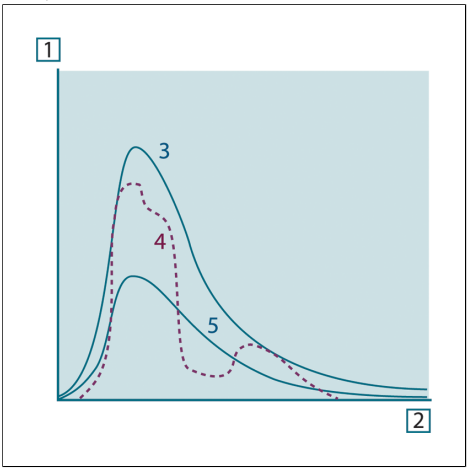


**Figure 19.8** Spectral radiant emittance of three types of radiators. **1:** Spectral radiant emittance; **2:** Wavelength; **3:** Blackbody; **4:** Selective radiator; **5:** Graybody.

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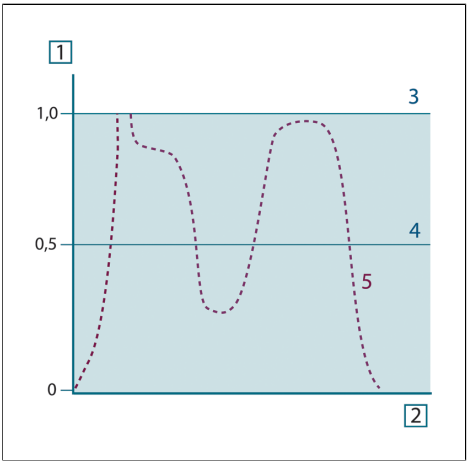


**Figure 19.9** Spectral emissivity of three types of radiators. **1:** Spectral emissivity; **2:** Wavelength; **3:** Blackbody; **4:** Graybody; **5:** Selective radiator.

## *19.4 Infrared semi-transparent materials*

Consider now a non-metallic, semi-transparent body – let us say, in the form of a thick flat plate of plastic material. When the plate is heated, radiation generated within its volume must work its way toward the surfaces through the material in which it is partially absorbed. Moreover, when it arrives at the surface, some of it is reflected back into the interior. The back-reflected radiation is again partially absorbed, but

some of it arrives at the other surface, through which most of it escapes; part of it is reflected back again. Although the progressive reflections become weaker and weaker they must all be added up when the total emittance of the plate is sought. When the resulting geometrical series is summed, the effective emissivity of a semi-transparent plate is obtained as:

$$\varepsilon_\lambda = \frac{(1-\rho_\lambda)(1-\tau_\lambda)}{1-\rho_\lambda\tau_\lambda}$$

When the plate becomes opaque this formula is reduced to the single formula:

$$\varepsilon_\lambda = 1-\rho_\lambda$$

This last relation is a particularly convenient one, because it is often easier to measure reflectance than to measure emissivity directly.

# 20 The measurement formula

As already mentioned, when viewing an object, the camera receives radiation not only from the object itself. It also collects radiation from the surroundings reflected via the object surface. Both these radiation contributions become attenuated to some extent by the atmosphere in the measurement path. To this comes a third radiation contribution from the atmosphere itself.

This description of the measurement situation, as illustrated in the figure below, is so far a fairly true description of the real conditions. What has been neglected could for instance be sun light scattering in the atmosphere or stray radiation from intense radiation sources outside the field of view. Such disturbances are difficult to quantify, however, in most cases they are fortunately small enough to be neglected. In case they are not negligible, the measurement configuration is likely to be such that the risk for disturbance is obvious, at least to a trained operator. It is then his responsibility to modify the measurement situation to avoid the disturbance e.g. by changing the viewing direction, shielding off intense radiation sources etc.

Accepting the description above, we can use the figure below to derive a formula for the calculation of the object temperature from the calibrated camera output.

10400503;a1

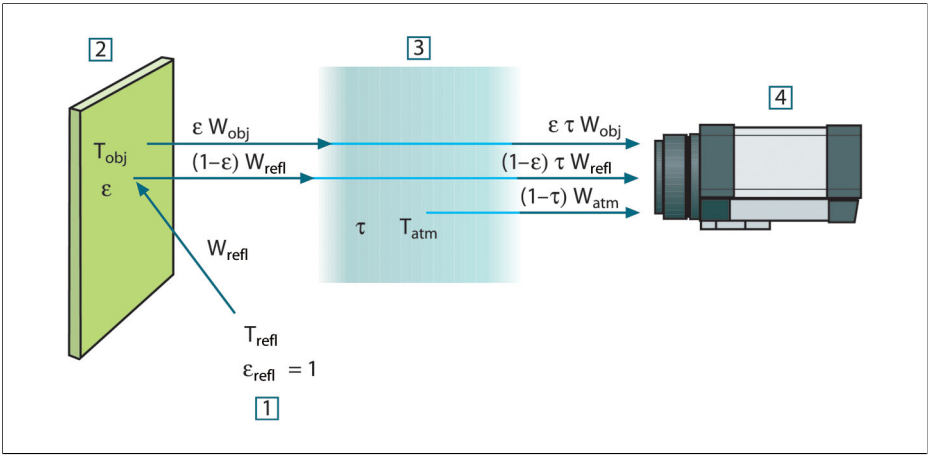


**Figure 20.1** A schematic representation of the general thermographic measurement situation.**1:** Surroundings; **2:** Object; **3:** Atmosphere; **4:** Camera

Assume that the received radiation power W from a blackbody source of temperature $T_{source}$ on short distance generates a camera output signal $U_{source}$ that is proportional to the power input (power linear camera). We can then write (Equation 1):

$$U_{source} = CW(T_{source})$$

or, with simplified notation:

$$U_{source} = CW_{source}$$

where C is a constant.

Should the source be a graybody with emittance ε, the received radiation would consequently be $\varepsilon W_{source}$.

We are now ready to write the three collected radiation power terms:

*1 – Emission from the object* = $\varepsilon\tau W_{obj}$, where ε is the emittance of the object and τ is the transmittance of the atmosphere. The object temperature is $T_{obj}$.

*2 – Reflected emission from ambient sources* = $(1 - \varepsilon)\tau W_{refl}$, where (1 – ε) is the reflectance of the object. The ambient sources have the temperature $T_{refl}$.

It has here been assumed that the temperature $T_{refl}$ is the same for all emitting surfaces within the halfsphere seen from a point on the object surface. This is of course sometimes a simplification of the true situation. It is, however, a necessary simplification in order to derive a workable formula, and $T_{refl}$ can – at least theoretically – be given a value that represents an efficient temperature of a complex surrounding.

Note also that we have assumed that the emittance for the surroundings = 1. This is correct in accordance with Kirchhoff's law: All radiation impinging on the surrounding surfaces will eventually be absorbed by the same surfaces. Thus the emittance = 1. (Note though that the latest discussion requires the complete sphere around the object to be considered.)

*3 – Emission from the atmosphere* = $(1 - \tau)\tau W_{atm}$, where (1 – τ) is the emittance of the atmosphere. The temperature of the atmosphere is $T_{atm}$.

The total received radiation power can now be written (Equation 2):

$$W_{tot} = \varepsilon\tau W_{obj} + (1 - \varepsilon)\tau W_{refl} + (1 - \tau)W_{atm}$$

We multiply each term by the constant C of Equation 1 and replace the CW products by the corresponding U according to the same equation, and get (Equation 3):

$$U_{tot} = \varepsilon\tau U_{obj} + (1 - \varepsilon)\tau U_{refl} + (1 - \tau)U_{atm}$$

Solve Equation 3 for $U_{obj}$ (Equation 4):

$$U_{obj} = \frac{1}{\varepsilon\tau}U_{tot} - \frac{1-\varepsilon}{\varepsilon}U_{refl} - \frac{1-\tau}{\varepsilon\tau}U_{atm}$$

This is the general measurement formula used in all the FLIR Systems thermographic equipment. The voltages of the formula are:

**Figure 20.2** Voltages

| | |
|---|---|
| $U_{obj}$ | Calculated camera output voltage for a blackbody of temperature $T_{obj}$ i.e. a voltage that can be directly converted into true requested object temperature. |
| $U_{tot}$ | Measured camera output voltage for the actual case. |
| $U_{refl}$ | Theoretical camera output voltage for a blackbody of temperature $T_{refl}$ according to the calibration. |
| $U_{atm}$ | Theoretical camera output voltage for a blackbody of temperature $T_{atm}$ according to the calibration. |

The operator has to supply a number of parameter values for the calculation:

- the object emittance ε,
- the relative humidity,
- $T_{atm}$
- object distance ($D_{obj}$)
- the (effective) temperature of the object surroundings, or the reflected ambient temperature $T_{refl}$, and
- the temperature of the atmosphere $T_{atm}$

This task could sometimes be a heavy burden for the operator since there are normally no easy ways to find accurate values of emittance and atmospheric transmittance for the actual case. The two temperatures are normally less of a problem provided the surroundings do not contain large and intense radiation sources.

A natural question in this connection is: How important is it to know the right values of these parameters? It could though be of interest to get a feeling for this problem already here by looking into some different measurement cases and compare the relative magnitudes of the three radiation terms. This will give indications about when it is important to use correct values of which parameters.

The figures below illustrates the relative magnitudes of the three radiation contributions for three different object temperatures, two emittances, and two spectral ranges: SW and LW. Remaining parameters have the following fixed values:

- $\tau = 0.88$
- $T_{refl}$ = +20°C (+68°F)
- $T_{atm}$ = +20°C (+68°F)

It is obvious that measurement of low object temperatures are more critical than measuring high temperatures since the 'disturbing' radiation sources are relatively much stronger in the first case. Should also the object emittance be low, the situation would be still more difficult.

We have finally to answer a question about the importance of being allowed to use the calibration curve above the highest calibration point, what we call extrapolation. Imagine that we in a certain case measure $U_{tot} = 4.5$ volts. The highest calibration point for the camera was in the order of 4.1 volts, a value unknown to the operator. Thus, even if the object happened to be a blackbody, i.e. $U_{obj} = U_{tot}$, we are actually performing extrapolation of the calibration curve when converting 4.5 volts into temperature.

Let us now assume that the object is not black, it has an emittance of 0.75, and the transmittance is 0.92. We also assume that the two second terms of Equation 4 amount to 0.5 volts together. Computation of $U_{obj}$ by means of Equation 4 then results in $U_{obj} = 4.5 / 0.75 / 0.92 - 0.5 = 6.0$. This is a rather extreme extrapolation, particularly when considering that the video amplifier might limit the output to 5 volts! Note, though, that the application of the calibration curve is a theoretical procedure where no electronic or other limitations exist. We trust that if there had been no signal limitations in the camera, and if it had been calibrated far beyond 5 volts, the resulting curve would have been very much the same as our real curve extrapolated beyond 4.1 volts, provided the calibration algorithm is based on radiation physics, like the FLIR Systems algorithm. Of course there must be a limit to such extrapolations.

10400603;a2

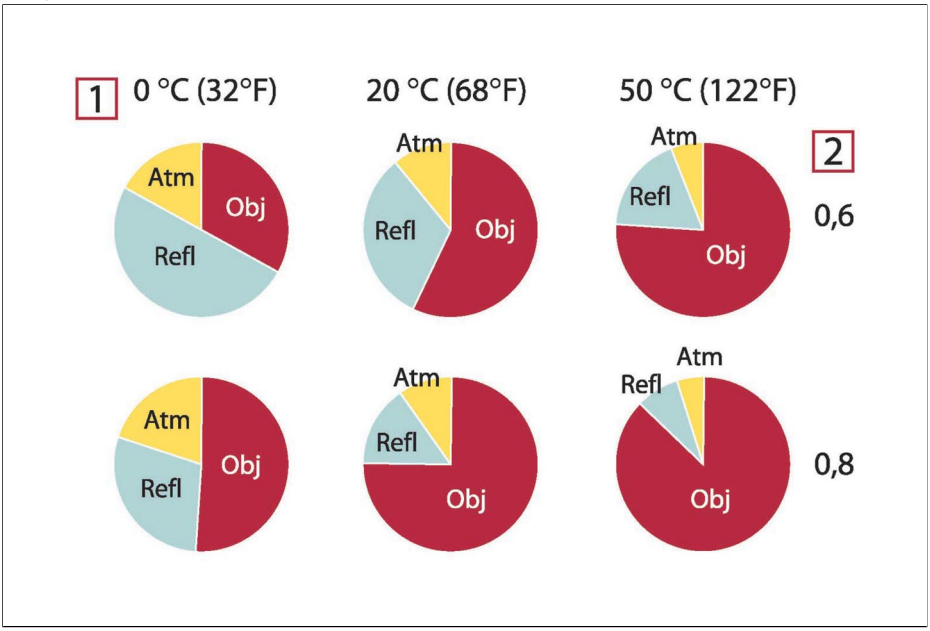


**Figure 20.3** Relative magnitudes of radiation sources under varying measurement conditions (SW camera). **1:** Object temperature; **2:** Emittance; **Obj:** Object radiation; **Refl:** Reflected radiation; **Atm:** atmosphere radiation. Fixed parameters: $\tau = 0.88$; $T_{refl} = 20°C$ (+68°F); $T_{atm} = 20°C$ (+68°F).

10400703;a2

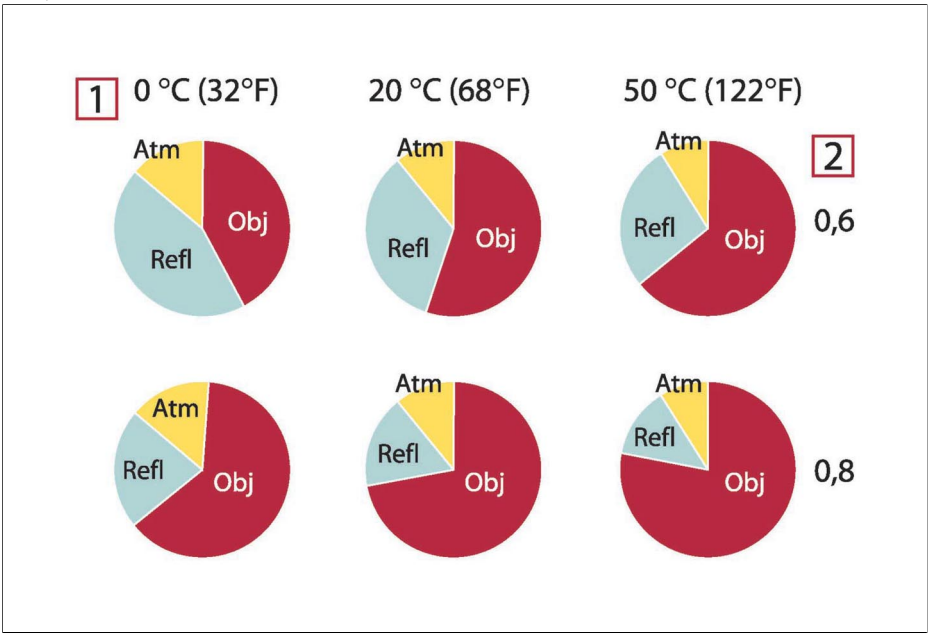


**Figure 20.4** Relative magnitudes of radiation sources under varying measurement conditions (LW camera). **1:** Object temperature; **2:** Emittance; **Obj:** Object radiation; **Refl:** Reflected radiation; **Atm:** atmosphere radiation. Fixed parameters: $\tau = 0.88$; $T_{refl} = 20°C$ (+68°F); $T_{atm} = 20°C$ (+68°F).

# 21 Emissivity tables

This section presents a compilation of emissivity data from the infrared literature and measurements made by FLIR Systems.

## *21.1 References*


| | |
|---|---|
| **1** | Mikaél A. Bramson: *Infrared Radiation, A Handbook for Applications*, Plenum press, N.Y. |
| **2** | William L. Wolfe, George J. Zissis: *The Infrared Handbook*, Office of Naval Research, Department of Navy, Washington, D.C. |
| **3** | Madding, R. P.: *Thermographic Instruments and systems*. Madison, Wisconsin: University of Wisconsin – Extension, Department of Engineering and Applied Science. |
| **4** | William L. Wolfe: *Handbook of Military Infrared Technology*, Office of Naval Research, Department of Navy, Washington, D.C. |
| **5** | Jones, Smith, Probert: *External thermography of buildings...,* Proc. of the Society of Photo-Optical Instrumentation Engineers, vol.110, Industrial and Civil Applications of Infrared Technology, June 1977 London. |
| **6** | Paljak, Pettersson: *Thermography of Buildings*, Swedish Building Research Institute, Stockholm 1972. |
| **7** | Vlcek, J: *Determination of emissivity with imaging radiometers and some emissivities at $\lambda = 5$ µm.* Photogrammetric Engineering and Remote Sensing. |
| **8** | Kern: *Evaluation of infrared emission of clouds and ground as measured by weather satellites*, Defence Documentation Center, AD 617 417. |
| **9** | Öhman, Claes: *Emittansmätningar med AGEMA E-Box*. Teknisk rapport, AGEMA 1999. (Emittance measurements using AGEMA E-Box. Technical report, AGEMA 1999.) |
| **10** | Matteï, S., Tang-Kwor, E: *Emissivity measurements for Nextel Velvet coating 811-21 between –36°C AND 82°C.* |
| **11** | Lohrengel & Todtenhaupt (1996) |
| **12** | ITC Technical publication 32. |
| **13** | ITC Technical publication 29. |


## *21.2 Important note about the emissivity tables*

The emissivity values in the table below are recorded using a shortwave (SW) camera. The values should be regarded as recommendations only and used with caution.

## 21.3 Tables

**Figure 21.1 T:** Total spectrum; **SW:** 2–5 $\mu$m; **LW:** 8–14 $\mu$m, **LLW:** 6.5–20 $\mu$m; **1:** Material; **2:** Specification; **3:** Temperature in °C; **4:** Spectrum; **5:** Emissivity: **6:** Reference

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 3M type 35 | Vinyl electrical tape (several colors) | < 80 | LW | Ca. 0.96 | 13 |
| 3M type 88 | Black vinyl electrical tape | < 105 | LW | Ca. 0.96 | 13 |
| 3M type 88 | Black vinyl electrical tape | < 105 | MW | < 0.96 | 13 |
| 3M type Super 33+ | Black vinyl electrical tape | < 80 | LW | Ca. 0.96 | 13 |
| Aluminum | anodized, black, dull | 70 | LW | 0.95 | 9 |
| Aluminum | anodized, black, dull | 70 | SW | 0.67 | 9 |
| Aluminum | anodized, light gray, dull | 70 | LW | 0.97 | 9 |
| Aluminum | anodized, light gray, dull | 70 | SW | 0.61 | 9 |
| Aluminum | anodized sheet | 100 | T | 0.55 | 2 |
| Aluminum | as received, plate | 100 | T | 0.09 | 4 |
| Aluminum | as received, sheet | 100 | T | 0.09 | 2 |
| Aluminum | cast, blast cleaned | 70 | LW | 0.46 | 9 |
| Aluminum | cast, blast cleaned | 70 | SW | 0.47 | 9 |
| Aluminum | dipped in $HNO_3$, plate | 100 | T | 0.05 | 4 |
| Aluminum | foil | 27 | 3 $\mu$m | 0.09 | 3 |
| Aluminum | foil | 27 | 10 $\mu$m | 0.04 | 3 |
| Aluminum | oxidized, strongly | 50–500 | T | 0.2–0.3 | 1 |
| Aluminum | polished | 50–100 | T | 0.04–0.06 | 1 |
| Aluminum | polished, sheet | 100 | T | 0.05 | 2 |
| Aluminum | polished plate | 100 | T | 0.05 | 4 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Aluminum | roughened | 27 | 3 $\mu$m | 0.28 | 3 |
| Aluminum | roughened | 27 | 10 $\mu$m | 0.18 | 3 |
| Aluminum | rough surface | 20–50 | T | 0.06–0.07 | 1 |
| Aluminum | sheet, 4 samples differently scratched | 70 | LW | 0.03–0.06 | 9 |
| Aluminum | sheet, 4 samples differently scratched | 70 | SW | 0.05–0.08 | 9 |
| Aluminum | vacuum deposited | 20 | T | 0.04 | 2 |
| Aluminum | weathered, heavily | 17 | SW | 0.83–0.94 | 5 |
| Aluminum bronze | | 20 | T | 0.60 | 1 |
| Aluminum hydroxide | powder | | T | 0.28 | 1 |
| Aluminum oxide | activated, powder | | T | 0.46 | 1 |
| Aluminum oxide | pure, powder (alumina) | | T | 0.16 | 1 |
| Asbestos | board | 20 | T | 0.96 | 1 |
| Asbestos | fabric | | T | 0.78 | 1 |
| Asbestos | floor tile | 35 | SW | 0.94 | 7 |
| Asbestos | paper | 40–400 | T | 0.93–0.95 | 1 |
| Asbestos | powder | | T | 0.40–0.60 | 1 |
| Asbestos | slate | 20 | T | 0.96 | 1 |
| Asphalt paving | | 4 | LLW | 0.967 | 8 |
| Brass | dull, tarnished | 20–350 | T | 0.22 | 1 |
| Brass | oxidized | 70 | SW | 0.04–0.09 | 9 |
| Brass | oxidized | 70 | LW | 0.03–0.07 | 9 |
| Brass | oxidized | 100 | T | 0.61 | 2 |
| Brass | oxidized at 600°C | 200–600 | T | 0.59–0.61 | 1 |
| Brass | polished | 200 | T | 0.03 | 1 |
| Brass | polished, highly | 100 | T | 0.03 | 2 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Brass | rubbed with 80-grit emery | 20 | T | 0.20 | 2 |
| Brass | sheet, rolled | 20 | T | 0.06 | 1 |
| Brass | sheet, worked with emery | 20 | T | 0.2 | 1 |
| Brick | alumina | 17 | SW | 0.68 | 5 |
| Brick | common | 17 | SW | 0.86–0.81 | 5 |
| Brick | Dinas silica, glazed, rough | 1100 | T | 0.85 | 1 |
| Brick | Dinas silica, refractory | 1000 | T | 0.66 | 1 |
| Brick | Dinas silica, unglazed, rough | 1000 | T | 0.80 | 1 |
| Brick | firebrick | 17 | SW | 0.68 | 5 |
| Brick | fireclay | 20 | T | 0.85 | 1 |
| Brick | fireclay | 1000 | T | 0.75 | 1 |
| Brick | fireclay | 1200 | T | 0.59 | 1 |
| Brick | masonry | 35 | SW | 0.94 | 7 |
| Brick | masonry, plastered | 20 | T | 0.94 | 1 |
| Brick | red, common | 20 | T | 0.93 | 2 |
| Brick | red, rough | 20 | T | 0.88–0.93 | 1 |
| Brick | refractory, corundum | 1000 | T | 0.46 | 1 |
| Brick | refractory, magnesite | 1000–1300 | T | 0.38 | 1 |
| Brick | refractory, strongly radiating | 500–1000 | T | 0.8–0.9 | 1 |
| Brick | refractory, weakly radiating | 500–1000 | T | 0.65–0.75 | 1 |
| Brick | silica, 95% $SiO_2$ | 1230 | T | 0.66 | 1 |
| Brick | sillimanite, 33% $SiO_2$, 64% $Al_2O_3$ | 1500 | T | 0.29 | 1 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Brick | waterproof | 17 | SW | 0.87 | 5 |
| Bronze | phosphor bronze | 70 | LW | 0.06 | 9 |
| Bronze | phosphor bronze | 70 | SW | 0.08 | 9 |
| Bronze | polished | 50 | T | 0.1 | 1 |
| Bronze | porous, rough | 50–150 | T | 0.55 | 1 |
| Bronze | powder | | T | 0.76–0.80 | 1 |
| Carbon | candle soot | 20 | T | 0.95 | 2 |
| Carbon | charcoal powder | | T | 0.96 | 1 |
| Carbon | graphite, filed surface | 20 | T | 0.98 | 2 |
| Carbon | graphite powder | | T | 0.97 | 1 |
| Carbon | lampblack | 20–400 | T | 0.95–0.97 | 1 |
| Chipboard | untreated | 20 | SW | 0.90 | 6 |
| Chromium | polished | 50 | T | 0.10 | 1 |
| Chromium | polished | 500–1000 | T | 0.28–0.38 | 1 |
| Clay | fired | 70 | T | 0.91 | 1 |
| Cloth | black | 20 | T | 0.98 | 1 |
| Concrete | | 20 | T | 0.92 | 2 |
| Concrete | dry | 36 | SW | 0.95 | 7 |
| Concrete | rough | 17 | SW | 0.97 | 5 |
| Concrete | walkway | 5 | LLW | 0.974 | 8 |
| Copper | commercial, burnished | 20 | T | 0.07 | 1 |
| Copper | electrolytic, carefully polished | 80 | T | 0.018 | 1 |
| Copper | electrolytic, polished | –34 | T | 0.006 | 4 |
| Copper | molten | 1100–1300 | T | 0.13–0.15 | 1 |
| Copper | oxidized | 50 | T | 0.6–0.7 | 1 |
| Copper | oxidized, black | 27 | T | 0.78 | 4 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Copper | oxidized, heavily | 20 | T | 0.78 | 2 |
| Copper | oxidized to blackness | | T | 0.88 | 1 |
| Copper | polished | 50–100 | T | 0.02 | 1 |
| Copper | polished | 100 | T | 0.03 | 2 |
| Copper | polished, commercial | 27 | T | 0.03 | 4 |
| Copper | polished, mechanical | 22 | T | 0.015 | 4 |
| Copper | pure, carefully prepared surface | 22 | T | 0.008 | 4 |
| Copper | scraped | 27 | T | 0.07 | 4 |
| Copper dioxide | powder | | T | 0.84 | 1 |
| Copper oxide | red, powder | | T | 0.70 | 1 |
| Ebonite | | | T | 0.89 | 1 |
| Emery | coarse | 80 | T | 0.85 | 1 |
| Enamel | | 20 | T | 0.9 | 1 |
| Enamel | lacquer | 20 | T | 0.85–0.95 | 1 |
| Fiber board | hard, untreated | 20 | SW | 0.85 | 6 |
| Fiber board | masonite | 70 | LW | 0.88 | 9 |
| Fiber board | masonite | 70 | SW | 0.75 | 9 |
| Fiber board | particle board | 70 | LW | 0.89 | 9 |
| Fiber board | particle board | 70 | SW | 0.77 | 9 |
| Fiber board | porous, untreated | 20 | SW | 0.85 | 6 |
| Gold | polished | 130 | T | 0.018 | 1 |
| Gold | polished, carefully | 200–600 | T | 0.02–0.03 | 1 |
| Gold | polished, highly | 100 | T | 0.02 | 2 |
| Granite | polished | 20 | LLW | 0.849 | 8 |
| Granite | rough | 21 | LLW | 0.879 | 8 |
| Granite | rough, 4 different samples | 70 | LW | 0.77–0.87 | 9 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Granite | rough, 4 different samples | 70 | SW | 0.95–0.97 | 9 |
| Gypsum | | 20 | T | 0.8–0.9 | 1 |
| Ice: See Water | | | | | |
| Iron, cast | casting | 50 | T | 0.81 | 1 |
| Iron, cast | ingots | 1000 | T | 0.95 | 1 |
| Iron, cast | liquid | 1300 | T | 0.28 | 1 |
| Iron, cast | machined | 800–1000 | T | 0.60–0.70 | 1 |
| Iron, cast | oxidized | 38 | T | 0.63 | 4 |
| Iron, cast | oxidized | 100 | T | 0.64 | 2 |
| Iron, cast | oxidized | 260 | T | 0.66 | 4 |
| Iron, cast | oxidized | 538 | T | 0.76 | 4 |
| Iron, cast | oxidized at 600°C | 200–600 | T | 0.64–0.78 | 1 |
| Iron, cast | polished | 38 | T | 0.21 | 4 |
| Iron, cast | polished | 40 | T | 0.21 | 2 |
| Iron, cast | polished | 200 | T | 0.21 | 1 |
| Iron, cast | unworked | 900–1100 | T | 0.87–0.95 | 1 |
| Iron and steel | cold rolled | 70 | LW | 0.09 | 9 |
| Iron and steel | cold rolled | 70 | SW | 0.20 | 9 |
| Iron and steel | covered with red rust | 20 | T | 0.61–0.85 | 1 |
| Iron and steel | electrolytic | 22 | T | 0.05 | 4 |
| Iron and steel | electrolytic | 100 | T | 0.05 | 4 |
| Iron and steel | electrolytic | 260 | T | 0.07 | 4 |
| Iron and steel | electrolytic, carefully polished | 175–225 | T | 0.05–0.06 | 1 |
| Iron and steel | freshly worked with emery | 20 | T | 0.24 | 1 |
| Iron and steel | ground sheet | 950–1100 | T | 0.55–0.61 | 1 |
| Iron and steel | heavily rusted sheet | 20 | T | 0.69 | 2 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Iron and steel | hot rolled | 20 | T | 0.77 | 1 |
| Iron and steel | hot rolled | 130 | T | 0.60 | 1 |
| Iron and steel | oxidized | 100 | T | 0.74 | 1 |
| Iron and steel | oxidized | 100 | T | 0.74 | 4 |
| Iron and steel | oxidized | 125–525 | T | 0.78–0.82 | 1 |
| Iron and steel | oxidized | 200 | T | 0.79 | 2 |
| Iron and steel | oxidized | 1227 | T | 0.89 | 4 |
| Iron and steel | oxidized | 200–600 | T | 0.80 | 1 |
| Iron and steel | oxidized strongly | 50 | T | 0.88 | 1 |
| Iron and steel | oxidized strongly | 500 | T | 0.98 | 1 |
| Iron and steel | polished | 100 | T | 0.07 | 2 |
| Iron and steel | polished | 400–1000 | T | 0.14–0.38 | 1 |
| Iron and steel | polished sheet | 750–1050 | T | 0.52–0.56 | 1 |
| Iron and steel | rolled, freshly | 20 | T | 0.24 | 1 |
| Iron and steel | rolled sheet | 50 | T | 0.56 | 1 |
| Iron and steel | rough, plane surface | 50 | T | 0.95–0.98 | 1 |
| Iron and steel | rusted, heavily | 17 | SW | 0.96 | 5 |
| Iron and steel | rusted red, sheet | 22 | T | 0.69 | 4 |
| Iron and steel | rusty, red | 20 | T | 0.69 | 1 |
| Iron and steel | shiny, etched | 150 | T | 0.16 | 1 |
| Iron and steel | shiny oxide layer, sheet, | 20 | T | 0.82 | 1 |
| Iron and steel | wrought, carefully polished | 40–250 | T | 0.28 | 1 |
| Iron galvanized | heavily oxidized | 70 | LW | 0.85 | 9 |
| Iron galvanized | heavily oxidized | 70 | SW | 0.64 | 9 |
| Iron galvanized | sheet | 92 | T | 0.07 | 4 |
| Iron galvanized | sheet, burnished | 30 | T | 0.23 | 1 |
| Iron galvanized | sheet, oxidized | 20 | T | 0.28 | 1 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Iron tinned | sheet | 24 | T | 0.064 | 4 |
| Krylon Ultra-flat black 1602 | Flat black | Room temperature up to 175 | LW | Ca. 0.96 | 12 |
| Krylon Ultra-flat black 1602 | Flat black | Room temperature up to 175 | MW | Ca. 0.97 | 12 |
| Lacquer | 3 colors sprayed on Aluminum | 70 | LW | 0.92–0.94 | 9 |
| Lacquer | 3 colors sprayed on Aluminum | 70 | SW | 0.50–0.53 | 9 |
| Lacquer | Aluminum on rough surface | 20 | T | 0.4 | 1 |
| Lacquer | bakelite | 80 | T | 0.83 | 1 |
| Lacquer | black, dull | 40–100 | T | 0.96–0.98 | 1 |
| Lacquer | black, matte | 100 | T | 0.97 | 2 |
| Lacquer | black, shiny, sprayed on iron | 20 | T | 0.87 | 1 |
| Lacquer | heat–resistant | 100 | T | 0.92 | 1 |
| Lacquer | white | 40–100 | T | 0.8–0.95 | 1 |
| Lacquer | white | 100 | T | 0.92 | 2 |
| Lead | oxidized, gray | 20 | T | 0.28 | 1 |
| Lead | oxidized, gray | 22 | T | 0.28 | 4 |
| Lead | oxidized at 200°C | 200 | T | 0.63 | 1 |
| Lead | shiny | 250 | T | 0.08 | 1 |
| Lead | unoxidized, polished | 100 | T | 0.05 | 4 |
| Lead red | | 100 | T | 0.93 | 4 |
| Lead red, powder | | 100 | T | 0.93 | 1 |
| Leather | tanned | | T | 0.75–0.80 | 1 |
| Lime | | | T | 0.3–0.4 | 1 |
| Magnesium | | 22 | T | 0.07 | 4 |
| Magnesium | | 260 | T | 0.13 | 4 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Magnesium | | 538 | T | 0.18 | 4 |
| Magnesium | polished | 20 | T | 0.07 | 2 |
| Magnesium powder | | | T | 0.86 | 1 |
| Molybdenum | | 600–1000 | T | 0.08–0.13 | 1 |
| Molybdenum | | 1500–2200 | T | 0.19–0.26 | 1 |
| Molybdenum | filament | 700–2500 | T | 0.1–0.3 | 1 |
| Mortar | | 17 | SW | 0.87 | 5 |
| Mortar | dry | 36 | SW | 0.94 | 7 |
| Nextel Velvet 811-21 Black | Flat black | –60–150 | LW | > 0.97 | 10 and 11 |
| Nichrome | rolled | 700 | T | 0.25 | 1 |
| Nichrome | sandblasted | 700 | T | 0.70 | 1 |
| Nichrome | wire, clean | 50 | T | 0.65 | 1 |
| Nichrome | wire, clean | 500–1000 | T | 0.71–0.79 | 1 |
| Nichrome | wire, oxidized | 50–500 | T | 0.95–0.98 | 1 |
| Nickel | bright matte | 122 | T | 0.041 | 4 |
| Nickel | commercially pure, polished | 100 | T | 0.045 | 1 |
| Nickel | commercially pure, polished | 200–400 | T | 0.07–0.09 | 1 |
| Nickel | electrolytic | 22 | T | 0.04 | 4 |
| Nickel | electrolytic | 38 | T | 0.06 | 4 |
| Nickel | electrolytic | 260 | T | 0.07 | 4 |
| Nickel | electrolytic | 538 | T | 0.10 | 4 |
| Nickel | electroplated, polished | 20 | T | 0.05 | 2 |
| Nickel | electroplated on iron, polished | 22 | T | 0.045 | 4 |
| Nickel | electroplated on iron, unpolished | 20 | T | 0.11–0.40 | 1 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Nickel | electroplated on iron, unpolished | 22 | T | 0.11 | 4 |
| Nickel | oxidized | 200 | T | 0.37 | 2 |
| Nickel | oxidized | 227 | T | 0.37 | 4 |
| Nickel | oxidized | 1227 | T | 0.85 | 4 |
| Nickel | oxidized at 600°C | 200–600 | T | 0.37–0.48 | 1 |
| Nickel | polished | 122 | T | 0.045 | 4 |
| Nickel | wire | 200–1000 | T | 0.1–0.2 | 1 |
| Nickel oxide | | 500–650 | T | 0.52–0.59 | 1 |
| Nickel oxide | | 1000–1250 | T | 0.75–0.86 | 1 |
| Oil, lubricating | 0.025 mm film | 20 | T | 0.27 | 2 |
| Oil, lubricating | 0.050 mm film | 20 | T | 0.46 | 2 |
| Oil, lubricating | 0.125 mm film | 20 | T | 0.72 | 2 |
| Oil, lubricating | film on Ni base: Ni base only | 20 | T | 0.05 | 2 |
| Oil, lubricating | thick coating | 20 | T | 0.82 | 2 |
| Paint | 8 different colors and qualities | 70 | LW | 0.92–0.94 | 9 |
| Paint | 8 different colors and qualities | 70 | SW | 0.88–0.96 | 9 |
| Paint | Aluminum, various ages | 50–100 | T | 0.27–0.67 | 1 |
| Paint | cadmium yellow | | T | 0.28–0.33 | 1 |
| Paint | chrome green | | T | 0.65–0.70 | 1 |
| Paint | cobalt blue | | T | 0.7–0.8 | 1 |
| Paint | oil | 17 | SW | 0.87 | 5 |
| Paint | oil, black flat | 20 | SW | 0.94 | 6 |
| Paint | oil, black gloss | 20 | SW | 0.92 | 6 |
| Paint | oil, gray flat | 20 | SW | 0.97 | 6 |
| Paint | oil, gray gloss | 20 | SW | 0.96 | 6 |
| Paint | oil, various colors | 100 | T | 0.92–0.96 | 1 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Paint | oil based, average of 16 colors | 100 | T | 0.94 | 2 |
| Paint | plastic, black | 20 | SW | 0.95 | 6 |
| Paint | plastic, white | 20 | SW | 0.84 | 6 |
| Paper | 4 different colors | 70 | LW | 0.92–0.94 | 9 |
| Paper | 4 different colors | 70 | SW | 0.68–0.74 | 9 |
| Paper | black | | T | 0.90 | 1 |
| Paper | black, dull | | T | 0.94 | 1 |
| Paper | black, dull | 70 | LW | 0.89 | 9 |
| Paper | black, dull | 70 | SW | 0.86 | 9 |
| Paper | blue, dark | | T | 0.84 | 1 |
| Paper | coated with black lacquer | | T | 0.93 | 1 |
| Paper | green | | T | 0.85 | 1 |
| Paper | red | | T | 0.76 | 1 |
| Paper | white | 20 | T | 0.7–0.9 | 1 |
| Paper | white, 3 different glosses | 70 | LW | 0.88–0.90 | 9 |
| Paper | white, 3 different glosses | 70 | SW | 0.76–0.78 | 9 |
| Paper | white bond | 20 | T | 0.93 | 2 |
| Paper | yellow | | T | 0.72 | 1 |
| Plaster | | 17 | SW | 0.86 | 5 |
| Plaster | plasterboard, untreated | 20 | SW | 0.90 | 6 |
| Plaster | rough coat | 20 | T | 0.91 | 2 |
| Plastic | glass fibre laminate (printed circ. board) | 70 | LW | 0.91 | 9 |
| Plastic | glass fibre laminate (printed circ. board) | 70 | SW | 0.94 | 9 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Plastic | polyurethane isolation board | 70 | LW | 0.55 | 9 |
| Plastic | polyurethane isolation board | 70 | SW | 0.29 | 9 |
| Plastic | PVC, plastic floor, dull, structured | 70 | LW | 0.93 | 9 |
| Plastic | PVC, plastic floor, dull, structured | 70 | SW | 0.94 | 9 |
| Platinum | | 17 | T | 0.016 | 4 |
| Platinum | | 22 | T | 0.03 | 4 |
| Platinum | | 100 | T | 0.05 | 4 |
| Platinum | | 260 | T | 0.06 | 4 |
| Platinum | | 538 | T | 0.10 | 4 |
| Platinum | | 1000–1500 | T | 0.14–0.18 | 1 |
| Platinum | | 1094 | T | 0.18 | 4 |
| Platinum | pure, polished | 200–600 | T | 0.05–0.10 | 1 |
| Platinum | ribbon | 900–1100 | T | 0.12–0.17 | 1 |
| Platinum | wire | 50–200 | T | 0.06–0.07 | 1 |
| Platinum | wire | 500–1000 | T | 0.10–0.16 | 1 |
| Platinum | wire | 1400 | T | 0.18 | 1 |
| Porcelain | glazed | 20 | T | 0.92 | 1 |
| Porcelain | white, shiny | | T | 0.70–0.75 | 1 |
| Rubber | hard | 20 | T | 0.95 | 1 |
| Rubber | soft, gray, rough | 20 | T | 0.95 | 1 |
| Sand | | | T | 0.60 | 1 |
| Sand | | 20 | T | 0.90 | 2 |
| Sandstone | polished | 19 | LLW | 0.909 | 8 |
| Sandstone | rough | 19 | LLW | 0.935 | 8 |
| Silver | polished | 100 | T | 0.03 | 2 |
| Silver | pure, polished | 200–600 | T | 0.02–0.03 | 1 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Skin | human | 32 | T | 0.98 | 2 |
| Slag | boiler | 0–100 | T | 0.97–0.93 | 1 |
| Slag | boiler | 200–500 | T | 0.89–0.78 | 1 |
| Slag | boiler | 600–1200 | T | 0.76–0.70 | 1 |
| Slag | boiler | 1400–1800 | T | 0.69–0.67 | 1 |
| Snow: See Water | | | | | |
| Soil | dry | 20 | T | 0.92 | 2 |
| Soil | saturated with water | 20 | T | 0.95 | 2 |
| Stainless steel | alloy, 8% Ni, 18% Cr | 500 | T | 0.35 | 1 |
| Stainless steel | rolled | 700 | T | 0.45 | 1 |
| Stainless steel | sandblasted | 700 | T | 0.70 | 1 |
| Stainless steel | sheet, polished | 70 | LW | 0.14 | 9 |
| Stainless steel | sheet, polished | 70 | SW | 0.18 | 9 |
| Stainless steel | sheet, untreated, somewhat scratched | 70 | LW | 0.28 | 9 |
| Stainless steel | sheet, untreated, somewhat scratched | 70 | SW | 0.30 | 9 |
| Stainless steel | type 18-8, buffed | 20 | T | 0.16 | 2 |
| Stainless steel | type 18-8, oxidized at 800°C | 60 | T | 0.85 | 2 |
| Stucco | rough, lime | 10–90 | T | 0.91 | 1 |
| Styrofoam | insulation | 37 | SW | 0.60 | 7 |
| Tar | | | T | 0.79–0.84 | 1 |
| Tar | paper | 20 | T | 0.91–0.93 | 1 |
| Tile | glazed | 17 | SW | 0.94 | 5 |
| Tin | burnished | 20–50 | T | 0.04–0.06 | 1 |
| Tin | tin–plated sheet iron | 100 | T | 0.07 | 2 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Titanium | oxidized at 540°C | 200 | T | 0.40 | 1 |
| Titanium | oxidized at 540°C | 500 | T | 0.50 | 1 |
| Titanium | oxidized at 540°C | 1000 | T | 0.60 | 1 |
| Titanium | polished | 200 | T | 0.15 | 1 |
| Titanium | polished | 500 | T | 0.20 | 1 |
| Titanium | polished | 1000 | T | 0.36 | 1 |
| Tungsten | | 200 | T | 0.05 | 1 |
| Tungsten | | 600–1000 | T | 0.1–0.16 | 1 |
| Tungsten | | 1500–2200 | T | 0.24–0.31 | 1 |
| Tungsten | filament | 3300 | T | 0.39 | 1 |
| Varnish | flat | 20 | SW | 0.93 | 6 |
| Varnish | on oak parquet floor | 70 | LW | 0.90–0.93 | 9 |
| Varnish | on oak parquet floor | 70 | SW | 0.90 | 9 |
| Wallpaper | slight pattern, light gray | 20 | SW | 0.85 | 6 |
| Wallpaper | slight pattern, red | 20 | SW | 0.90 | 6 |
| Water | distilled | 20 | T | 0.96 | 2 |
| Water | frost crystals | –10 | T | 0.98 | 2 |
| Water | ice, covered with heavy frost | 0 | T | 0.98 | 1 |
| Water | ice, smooth | –10 | T | 0.96 | 2 |
| Water | ice, smooth | 0 | T | 0.97 | 1 |
| Water | layer >0.1 mm thick | 0–100 | T | 0.95–0.98 | 1 |
| Water | snow | | T | 0.8 | 1 |
| Water | snow | –10 | T | 0.85 | 2 |
| Wood | | 17 | SW | 0.98 | 5 |
| Wood | | 19 | LLW | 0.962 | 8 |
| Wood | ground | | T | 0.5–0.7 | 1 |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Wood | pine, 4 different samples | 70 | LW | 0.81–0.89 | 9 |
| Wood | pine, 4 different samples | 70 | SW | 0.67–0.75 | 9 |
| Wood | planed | 20 | T | 0.8–0.9 | 1 |
| Wood | planed oak | 20 | T | 0.90 | 2 |
| Wood | planed oak | 70 | LW | 0.88 | 9 |
| Wood | planed oak | 70 | SW | 0.77 | 9 |
| Wood | plywood, smooth, dry | 36 | SW | 0.82 | 7 |
| Wood | plywood, untreated | 20 | SW | 0.83 | 6 |
| Wood | white, damp | 20 | T | 0.7–0.8 | 1 |
| Zinc | oxidized at 400°C | 400 | T | 0.11 | 1 |
| Zinc | oxidized surface | 1000–1200 | T | 0.50–0.60 | 1 |
| Zinc | polished | 200–300 | T | 0.04–0.05 | 1 |
| Zinc | sheet | 50 | T | 0.20 | 1 |

**A note on the technical production of this publication**

This publication was produced using XML—the e*Xtensible Markup Language*. For more information about XML, please visit http://www.w3.org/XML/

**A note on the typeface used in this publication**

This publication was typeset using Swiss 721, which is Bitstream's pan-European version of the Helvetica™ typeface. Helvetica™ was designed by Max Miedinger (1910–1980).

**List of effective files**

20235103.xml a24
20235203.xml a21
20235303.xml a18
20236703.xml a47
20237103.xml a10
20238503.xml a9
20238703.xml b8
20250403.xml a19
20254903.xml a62
20257003.xml a40
20279803.xml a7
20287303.xml a8
20291703.xml a10
20291803.xml a14
20291903.xml a9
20292003.xml a9
20292103.xml a4
20292203.xml a5
20292303.xml a6
20292403.xml a4
20292503.xml a6
20294403.xml a5
20294703.xml a2
20294803.xml a1
R118.rcp a14
config.xml a5